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Evaluation of Foam Scrubbing as a Method for Collecting Fine Particulate

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16. ABSTRACT

The report summarizes the knowledge and data obtained during an investigation of foam scrubbing as a method for collecting fine particulate. The foam scrubber was tested at room temperature, using iron oxide aerosols at concentrations near 0.00137 mg/cu m. Inlet and outlet samples were taken with cascade impactors and toral mass filters. These tests were performed with different foam residence times and flow rates. A residence time of 35 seconds yielded a collection efficiency of 50%, while a residence time of 120 seconds yielded an efficiency of 95%. The operating cost of foam scrubbing with 99% surfactant recycle is an order of magnitude higher than that of the most expensive conventional method.

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Foam	Foam Scrubbers	11G
Dust	Particulate	
Iron Oxides		07B
Aerosols		07D
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by

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METRIC CONVERSIONS

To Convert From	To	Multiply By
foot	meter	1.05×10^{-1}
$foot^2$	$meter^2$	9.29×10^{-2}
$foot^3$	$meter^3$	2.83×10^{-2}
foot/min (fpm)	meter/sec	5.08×10^{-3}
ft/min (cfm)	$meter^3$/min	2.83×10^{-2}
gallon	liter	3.78
inch	cm	2.54
grains/ft^3	mg/m^3	2.29×10^{-3}
lb/min	g/min	4.54×10^{2}
lb/in^2 (psi)	newton/$meter^2$	6.89×10^{-3}
gallon/min (gpm)	liter/min	3.78

SECTION I

CONCLUSIONS

Results of testing a foam scrubbing apparatus indicate that foam scrubbing is a rather costly method for removing fine particulates from a gaseous stream. The apparatus consisted of a foam generator, a residence chamber, and a foam destructor. The foam was generated by passing a particulate laden gas stream through a screen wetted by a spray containing a surfactant liquid. The foam was destroyed by impacting it against the chamber walls, using a high-speed rotating disk. The method of generating and destroying foam was uncomplicated on a small scale, but problems could arise in designing a large scale scrubber.

The rate at which foam could be produced was limited by the velocity of the gaseous stream passing through the wetted screen. If the velocity were too high, the gas stream would pass through the wetted screen without generating foam, thus creating large voids or air pockets. Since the voids contained the dirty gas, the overall collection efficiency would decrease if the air pockets persisted. A good quality foam could not be produced at an air velocity over 15.5 m/min on the foam scrubber tested in this experiment.

The particle collection was experimentally verified for a fine particulate of iron oxide (Fe_2O_3). The bubble size for the tests was approximately 1.0 mm. To obtain a 99 percent collection efficiency in a foam produced with Tergitol surfactant, a residence time approaching 2 minutes was required.

A process flow rate of 100,000*acfm (2832 m^3/sec), and a residence time of 2 minutes would require a 1.5 million gallon (5.7 million liter) chamber volume to contain the foam. This high residence time would greatly increase the capital costs. In order for foam scrubbing to be competitive, in terms of capital investment with other conventional collection devices, the residence time must be less than 1 minute; however, at 2 minutes the capital cost would be only slightly higher than for an electrostatic precipitator, the most expensive conventional device.

*EPA policy is to use SI units only or to list both the common British Unit and its metric equivalent. For convenience and clarity, nonmetric units are used in this report. Readers more familiar with metric terms may use the conversion factors on page vi to convert to that system.

Although the capital cost may be competitive, the operating costs for foam scrubbing are likely to be much higher than for conventional devices. The higher operating costs are due mainly to the cost of the necessary surfactants. Even with a recycle of 99 percent of the surfactant liquid, foam scrubbing is an order of magnitude higher in operating cost than the most expensive conventional device.

SECTION II

RECOMMENDATIONS

Results of testing a small scale foam scrubber indicate that its operating costs will not be economical on a large scale. Although the capital cost of foam scrubbing will be close to that of conventional devices, its operating costs will be too high for the collection efficiencies obtained.

To be a viable method of fine particle control, the foam must be generated at a much higher rate and the quantity of surfactant used must be reduced considerably. Increasing the foam generation rate would reduce the overall size of the screen and would reduce the capital cost; however, any Δp increase will also increase operating costs. Increasing the surfactant recycle or reducing the quantity of surfactant used would reduce operating costs.

SECTION III

INTRODUCTION

Although various air pollution control devices are available to collect particulates, many of the devices are inadequate for removing submicron particles; those which do an adequate job consume large amounts of energy, require special maintenance, or are very large. Although available control devices offer mass removal efficiencies of over 99 percent, even these do not capture much of the fine particulate which passes into the atmosphere, creating air pollution problems.

One concept which shows promise in solving the problem of fine particulates is foam scrubbing. Foam scrubbing has been shown to effectively control submicron aerosol emissions on a small scale; however, a foam scrubber scaled up for industrial applications has not been tested.

Several different methods for producing foam for foam scrubbing are available. The foam can be generated by forcing gas through a liquid phase on a perforated plate as shown in Figure 1. The foam can also be generated by a nozzle arrangement such as used for producing foams with firefighting equipment. For this experiment, the foam was produced by a spray foam generator, with the foam generated in the gaseous phase. The apparatus is shown in Figure 2.

This program attempted to experimentally determine the feasibility of foam scrubbing as a viable method for removing submicron particles from gaseous streams and to assess the preliminary economics of foam scrubbing.

Figure 1. Perforated plate foam generator.

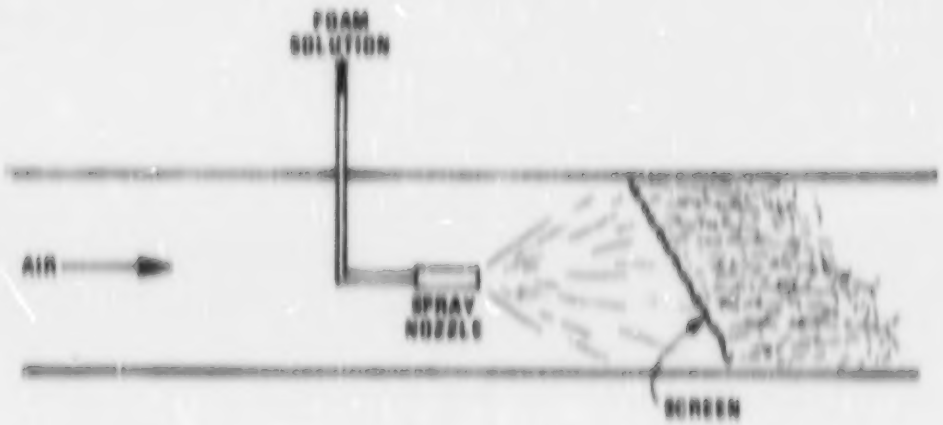

Figure 2. Spra[illegible]am generator.

SECTION IV

EXPERIMENTAL WORK

The three basic mechanisms for capturing particles inside a foam bubble are: (1) sedimentation, (2) inertial impaction, and (3) diffusion.[1] For submicron particles captured by the foam, diffusional capture and sedimentation (for particles greater than 0.1 μm) are the most evident.[2]

Not accounting for variables which would increase the random motion of the particles, the variables which would probably affect the chances of the particle striking the liquid interface of the foam and being captured are:

- Bubble size
- Residence time
- Foam stability
- Particle Size

Decreasing the bubble size should increase particle collection. Reducing the bubble diameter by a factor of 2 reduces the area of the liquid interface (Area = $4\pi r^2$) by a factor of 4, but also decreases the volume of gas inside the bubble ($V = 4/3\ \pi r^3$) by a factor of 8. Thus, halving the bubble diameter will give the same volume of gas a collecting area 6 times as great.

$$\frac{A}{V} = \frac{4\pi r^2}{4/3\ \pi r^3} = \frac{3}{r}$$

As the bubble size decreases, the time for capture is reduced since the average distance from the particle to the bubble wall is reduced. The particles inside the bubble are proportionally closer to the wall; so if the bubble diameter is halved, the capture time is also halved. Therefore, residence time is influenced strongly by bubble size and a reduction in bubble size should result in a shorter residence time in the scrubber.

By increasing residence time, the particles have more time in which to be captured by the foam. The foam must not degrade while in the chamber or efficiency will decrease. Degradation of the foam results in a larger bubble size and less efficiency.

Earlier work has shown that diffusional capture is theoretically the predominant mechanism for particle capture inside a bubble.[1,2] Basically, the diffusion of particles is caused by Brownian motion, the random motion of particles colliding with surrounding molecules. If the particle size decreases relative to the gas molecules, the velocity of the particle after each collision with a gas molecule must increase. A decrease in the particle size will result in an increase in the diffusion rate and the particle should strike the wall sooner than a larger particle. The diffusional coefficient of a 0.01 μm diameter is about 2,000 times larger than that of a 1.0 μm particle.[2]

The surfactant which was selected to produce the foam for this experiment was Tergitol TMN-6 manufactured by Union Carbide. The bubbles of the Tergitol-produced foam did not break appreciably during the several minutes residence time that the foam was inside the scrubber. The bubble size appeared to remain constant through the cycle.

Experimental Device

The experimental device to investigate the performance of foam scrubbing is shown in Figure 3. The particulate was produced with a metallizing spray gun (Wall Colmonoy Model VT-900). The Colmonoy Electrospray Metallizer utilized an electric arc to melt two metal wires fed continuously to the spray gun from two coils. A compressed air stream was directed through the arc zone to atomize the molten metal and propel the particles through the scrubbing system.

The particles were sprayed into a 55 gallon (208 liter) drum where the large molten metal particles settled out and the fine particulate as iron oxide (Fe_2O_3) was carried to the foam scrubbing apparatus. The air fed through the spray gun was sufficient to carry the particles to the foam generator and still produce a good quality foam.

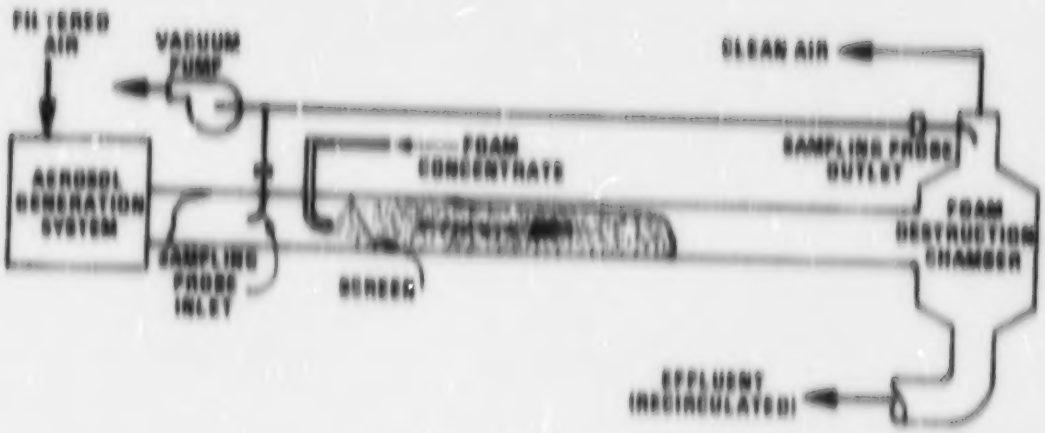

Figure 3. Foam scrubber system.

The foam generator consisted of a fine mesh wire screen placed at a 45° angle inside a 15.25 cm (6 inch) diameter Plexiglas tube. Two spray nozzles were used to spray a solution of surfactant onto the screen. The foam was produced when the air from the metallizing spray gun passed through the wetted screen. Various size screens were used but the highest quality foam was produced with a 270 mesh stainless steel screen. (A high quality foam is defined as a foam of uniform bubbles about 1.0 mm in diameter containing no air voids.)

Various spray nozzles were tested to determine which nozzle or combination of nozzles sprayed the surfactant solution onto the screen in the best pattern to completely wet the screen and produce the most uniform foam. The combination of nozzles finally selected to spray the surfactant solution was a 5 gph (0.315 l/min) 60° full spray nozzle and a 10 gph (0.630l/min) 60° full spray nozzle. The 10 gph nozzle was pointed to the center of the screen and located 12.0 cm (4.7 inch) from the screen. The 5 gph nozzle was located 6.3 cm (2.5 inch) in front of and 2.5 cm (1 inch) below the other nozzle but pointed toward the lower portion of the screen as shown in Figure 4.

Since two nozzles were required to completely wet the screen and to produce a good quality foam, more water was sprayed on the screen than was necessary to produce foam. The excess water prevented the screen from plugging and maintained a low pressure drop across the screen by continuously washing particles from the screen. The screen became plugged in less than 1 minute when the surfactant spray was discontinued.

After the foam was generated on the wire screen, the bubbles traveled down a 15.25 cm diameter Plexiglas tube where the particulate had sufficient time to contact the bubble wall and be captured in the foam. The length of the Plexiglas scrubber chamber was 5.8 m (19 ft) which was originally designed to be shortened by 1.8 m (6 ft) lengths to decrease the residence time in the chamber. During preliminary operation of the foam scrubber, it was determined that a longer (not shorter) residence time was required to obtain a high collection efficiency. To increase the residence time, the chamber was modified by adding a 1.8 m (6 ft) tube chamber as

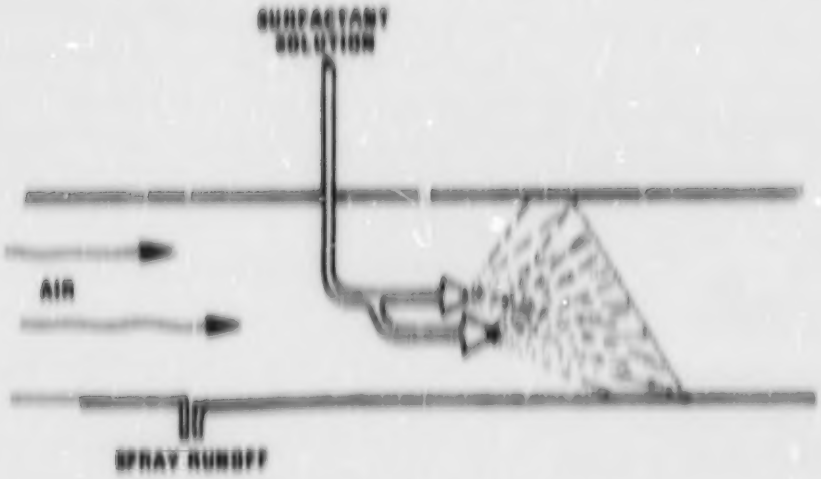

Figure 4. Nozzle arrangement for spraying surfactant on screen.

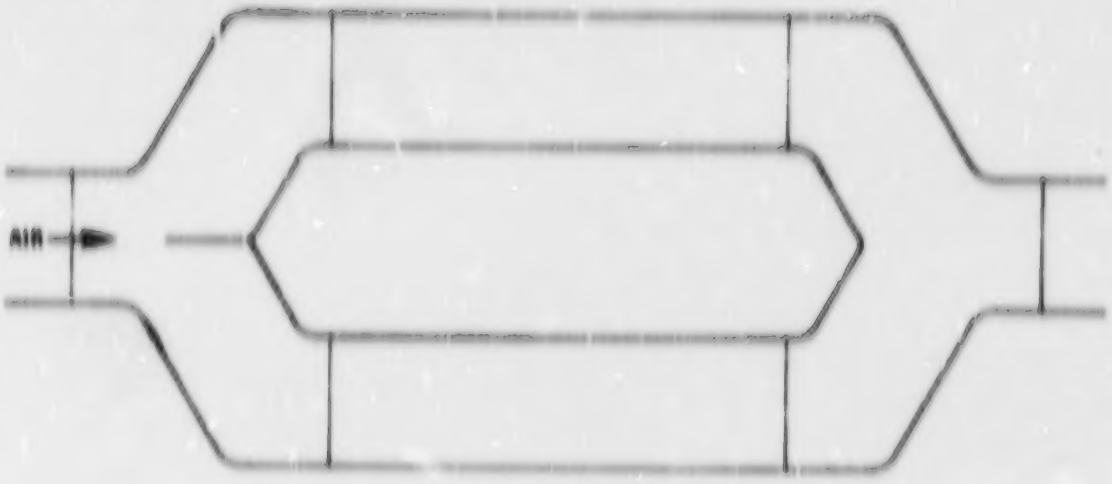

Figure 5. Extra chamber added to increase residence time.

shown in Figure 5 between the screen and destruction chamber. This extra section was necessitated since space limitations prevented the addition of extra sections lengthwise to the scrubbing chamber. The double-tube section increased the residence time by approximately 32 percent at the same foam velocity as through the single-tube chamber. The bubble size was unaffected by the modification in the residence chamber, and the only effect on the foam was the lower velocity through the double-tube section.

From the residence chamber, the foam entered the destruction chamber. The destruction chamber was simply a Teflon disk on a shaft inside a 15.25 cm (6 inch) galvanized duct. The disk configuration is shown in Figure 6. The disk was rotated at 5000 to 15,000 rpm impacting the foam against the duct wall, thereby breaking the foam bubbles. This type of foam destruction chamber was selected after trying many other foam breaking methods without success. (Heated steam coils, a flame directly on the foam, an air jet, and a water spray were tried; the method that destroyed the foam most efficiently and economically was the high-speed spinning disk.[2])

During preliminary testing, many modifications were made to the foam destruction chamber. Originally the disk was powered by a 50,000 rpm electric motor, via a flexible shaft. The disk could not be operated for more than several minutes without the disk separating from the shaft. Eventually the flexible shaft was replaced by a solid metal rod, centered in the destruction chamber. Unless the rod was perfectly straight, the disk would vibrate and hit the chamber walls. To prevent shaft vibration, the rod was centered in a 2.5 cm Teflon bushing, bolted into the destruction chamber as shown in Figure 7. With only minor problems, the foam destruction chamber performed satisfactorily during the remaining tests.

During the experiments, the liquid from the destroyed foam ran out of the bottom of the chamber and the cleaned air exited at the top of the chamber. The liquid, with the collected particulate and the screen runoff, was allowed to stand overnight to allow the solids to settle. All the liquid was recycled in this manner; the only liquid lost was the entrainment from the foam destructor.

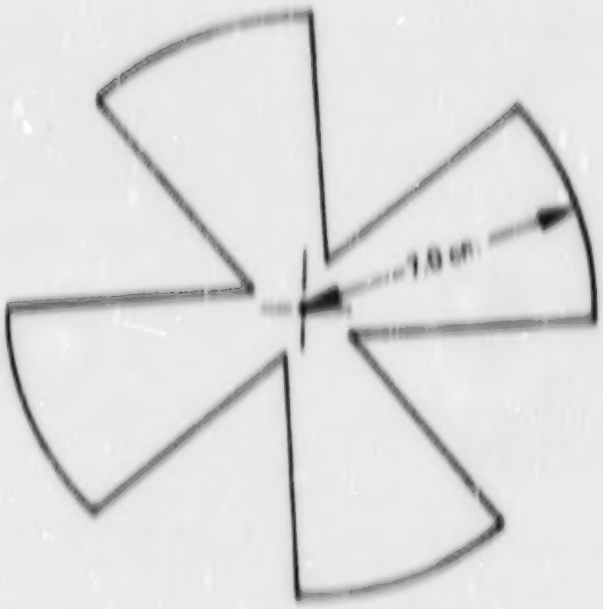

Figure 6. Foam destruction disk.

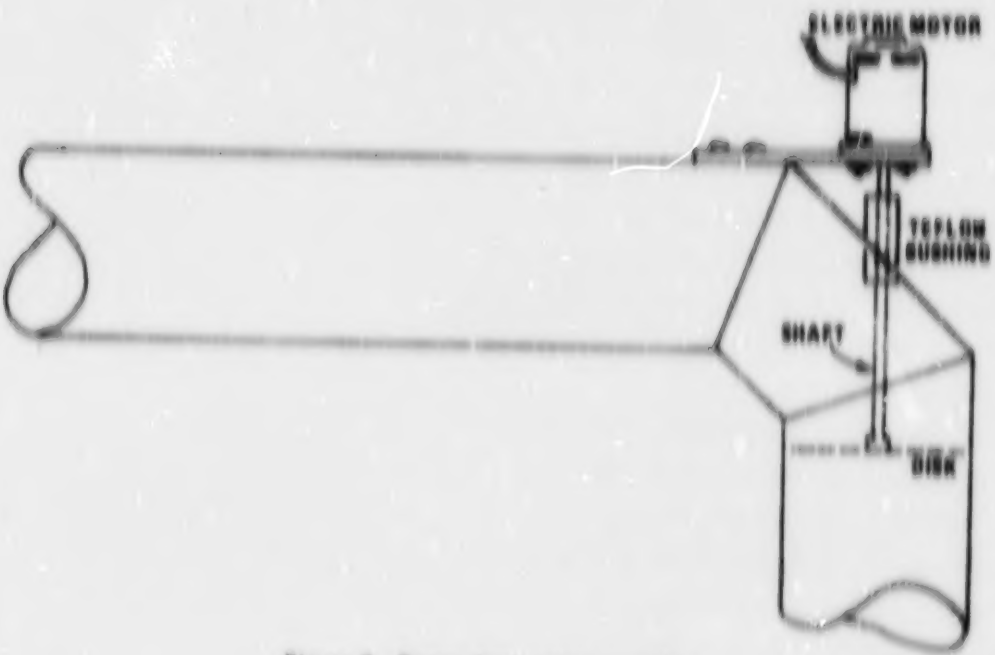

Figure 7. Foam destruction chamber.

Foam Scrubbing Tests

The foam scrubbing tests were an extension of earlier tests on a similar foam scrubber.[2] DOP and polypropylene glycol aerosols were used in the earlier tests to measure the efficiency, and the need still existed to test foam scrubbing on a solid particulate.

Preliminary tests were run on the foam scrubber to determine the optimum operating conditions for the particle generating system. These tests on the metallizing spray gun were run to determine the effect of spray pressure, voltage, and air flow on the size and number of particles produced. The particles generated by the metallizing spray gun were examined by X-ray diffraction and found to be essentially iron oxide (Fe_2O_3). The metallizing spray gun tests are discussed more fully in Appendix A.

After conditions for generation of an acceptable particulate were set, tests began on the foam scrubber. Initially, various conditions were tested to determine the operating limits for generation of a high quality foam (a foam with all bubbles aproximately 1 mm or smaller). At high air flows, the foam tended to have air pockets or voids in the foam which were about 5 cm in diameter or larger. Obtaining a small bubble size* was not as difficult as eliminating the large air pockets which traveled through the scrubber with the foam. The position of the spray nozzles was critical in controlling the air voids since the screen had to be wetted evenly to ensure constant foam formation. Complete wetting of the screen was necessary in order to prevent "holes" in the liquid on the screen where the air could blow through without generating foam; hence, the large air puckets.

The foam quality tended to improve after several minutes of operation with the metal fume generator operating. The iron oxide apparently plugged any unwetted areas of the screen, thereby forcing the air through the less restrictive wetted areas of the screen. Once a good quality foam was being produced, the foam quality remained constant until the nozzles or screen was altered; then the system had to be realigned.

*The bubble size was determined by collecting a sample of the foam and counting the number of bubbles per unit length.

The residence times which were tested for the foam are shown in Table 1. (Residence time is defined as the length of time the foam is in the scrubber--from the screen where the bubbles were generated to the destruction disk where the foam was destroyed.) Residence times were determined by measuring the velocity of the foam in the clear Plexiglas pipe, converting to residence time per unit length, and correcting for the total length.

To measure the particulate loading of the air stream before and after foam scrubbing, total mass determinations and impactor runs were made on all tests. The mass determinations were made with a Gelman type A Fiberglas filter sample. A Brink cascade impactor was used to measure the high inlet loadings and an Andersen impactor was used on the outlet. To compare the results of the two types of impactors, the Brink impactor was used on the outlet for several tests.

The sampling probe nozzles were placed 8 duct diameters from an upstream disturbance and greater than 5 duct diameters from a downstream disturbance. The sampling, therefore, was done at an excellent location in the duct. All of the impactor and total mass determinations were made at the center of the duct.

For the impactor runs, the samples were pulled as isokinetically as possible through the nozzle and probe to the impactor. Errors due to deviations from isokinetic sampling should be of little consequence for particles having aerodynamic diameters smaller than 5 um. Because of the small duct dimensions and the fine particulate being sampled, single point extractive sampling was utilized. The impactor sampling times were 2 minutes at the inlet and 10 or 15 minutes at the outlet to provide sufficient impactor stage loadings. Either grease or glass fiber substrates were used for the Brink impactor tests and glass fiber substrates for the Andersen impactor tests. The inlet Brink impactor runs were conducted at ambient temperature, but the impactors were heated to 120°C at the outlet to remove the water droplets carried over from the destruction chamber. All impactor data are given in Appendix B.

Since the captured particulate was removed from the used scrubber liquid (destroyed foam), a significant particle buildup did not occur.

Table 1. RESIDENCE TIMES AND AIR FLOWS FOR THE FOAM SCRUBBER TESTS

Rotameter Reading %	Flow Rate m^3/min (cfm)	Residence Time, sec		Foam Velocity[a]	
		Single Tube	Double Tube	m/min	(ft/min)
15	0.057 (2.0)	112	147	3.1	(10.2)
20	0.074 (2.6)	85	113	4.0	(13.2)
25	0.113 (4.0)	56	74	6.2	(20.4)
30	0.156 (5.5)	40	53	8.5	(28.0)
35	0.209 (7.4)	30	40	11.5	(37.6)
40[b]	0.283 (10.0)	22	29	15.5	(51.0)

[a]Foam velocity for single-tube section of modified system. The velocity will be halved in the double-tube section.

[b]Turbulence: large air pockets

If the liquid had been recycled without particle removal, the grain loading at the outlet would have been higher due to the extra solids carried over in the water droplets formed during foam destruction. Any droplets formed during destruction of particulate laden foam would have contributed to the exit grain loading to a substantial degree. A mist eliminator was not utilized after the foam destruction chamber, but the outlet concentration could have been reduced by adding some sort of mist control device.

SECTION V

RESULTS AND DISCUSSION

Particle collection is believed to occur in the foam scrubber at the bubble surfaces as the foam travels the length of the scrubbing chamber. By increasing the residence time, the number of particles striking the bubble wall will be increased and the total efficiency thereby increased. By decreasing the bubble size, the efficiency should also be increased; however, the effect of bubble size was not tested during these experiments. A 325 mesh screen was installed for testing, but a good quality foam could not be generated. Large air pockets were always present in the foam and all attempts to modify the system to obtain a better quality foam with the 325 mesh screen were futile. Whether the cause of the air pockets in the foam was due to the screen size, the spray nozzles, or the system as a whole was not determined.

Collection determinations were observed with the foam generated by the 270 mesh screen with different residence times. The addition of the 1.83 m section in the chamber allowed an increase in residence time without an increase in air flow through the scrubber. The mass filter determinations were used to calculate the overall efficiency of the foam scrubber; the results are shown in Figure 8. At residence times approaching 2 minutes, the overall collection efficiency approached 95.0%.

The lowest residence time before turbulence developed in the foam (35 sec) yielded a collection efficiency of about 58 percent. Lower residence times were not attempted because of the poor quality foam due to the large air pockets produced at the higher flow rates. The air pockets may have been present at a residence time of 35 sec, but they were not evident. When the pockets were visible, they were very noticeable and appeared very suddenly. Reducing the air flow always eliminated the pockets or at least they were not visible near the scrubber walls. The pockets may have occurred first in the center of the chamber where they could not be seen.

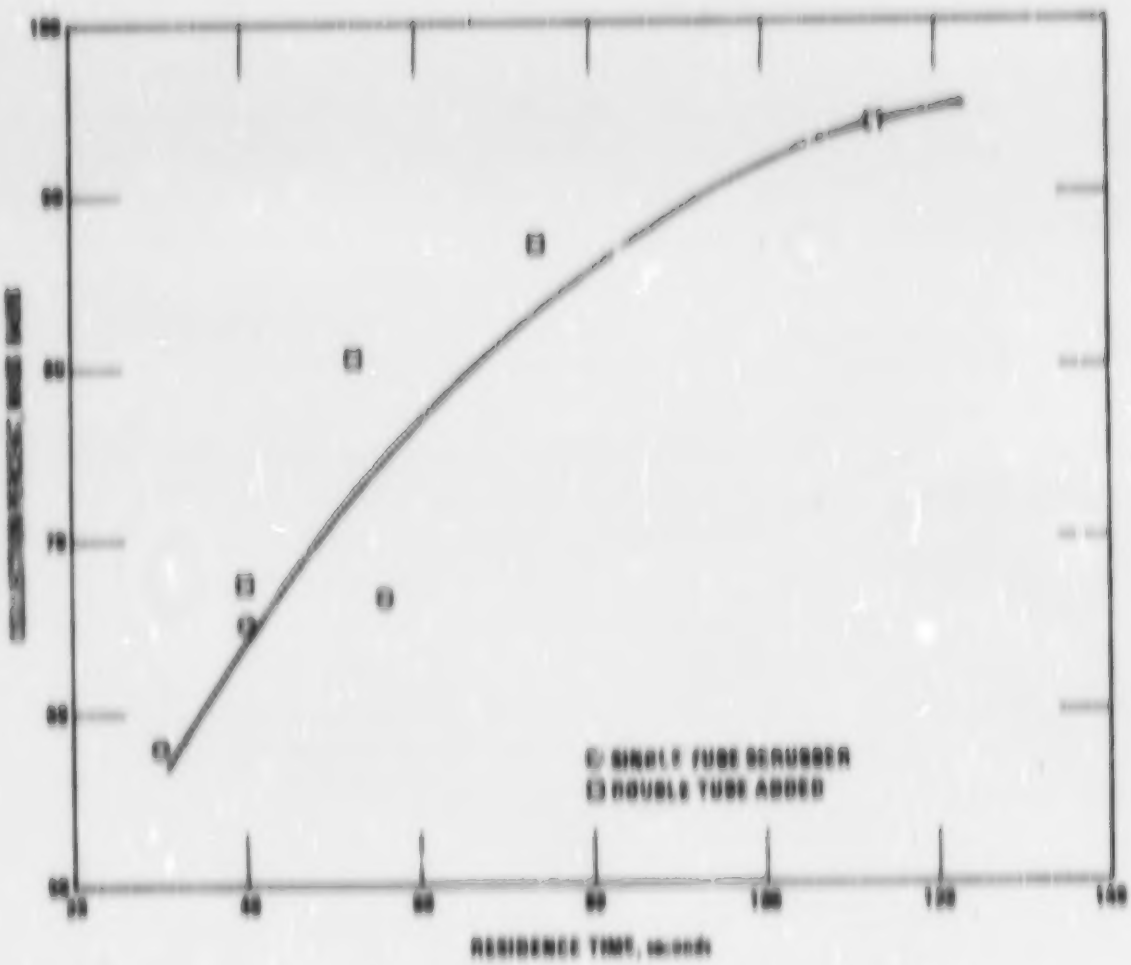

Figure 8. Collection efficiencies based on mass filter determinations.

Impactor Runs

The impactor data were reduced by means of a computer model.[3] The following parameters were calculated:

- Total mass collected (grams)
- Total volume of gas sampled (ft^3 at NTP)
- Particulate mass concentration (grains/dscf)
- Flow rate through impactor (acfm)
- 50 percent cutoff diameter for each stage for unit density spherical particles (μm)
- Mass percent on each stage (percent)
- Cumulative mass percent less than each stage cutoff diameter (percent)
- Geometric mean diameter for each stage interval (μm)
- dM/d log D for each stage interval (grains/dscf)

The data sheets for all the impactor runs are given in Appendix B.

To obtain the fractional efficiency for a test run, dM/d (log D) versus the geometric mean diameter is plotted for each stage interval for the inlet and outlet impactor tests. The curves from these graphs yield the concentration for any given size particle. The ratio of the outlet concentration to the inlet concentration for any size particle is the penetration for that particular size.

The inlet and outlet concentrations for various residence times are shown in Figures 9, 10, 11, and 12 and the penetration is shown in Figure 13.

The Figure 13 curves show that the penetration reaches a minimum at an aerodynamic particle diameter of approximately 2 to 3 microns. This minimum point in the penetration curves may be the result of an entrainment problem since foam scrubbing theoretically should work most effectively with the very small particles.

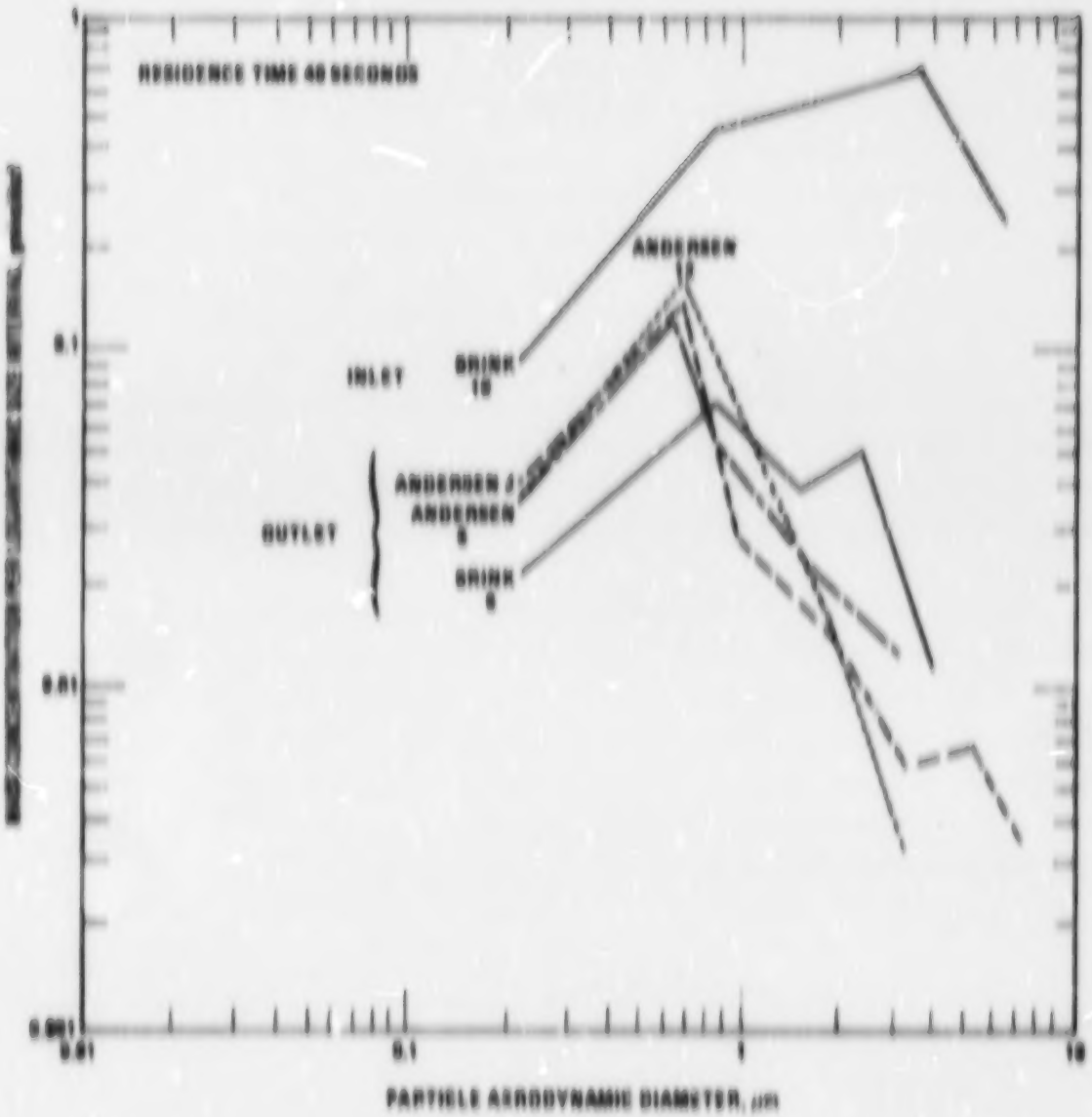

Figure 9. Inlet and outlet concentration distributions for 40 second residence time.

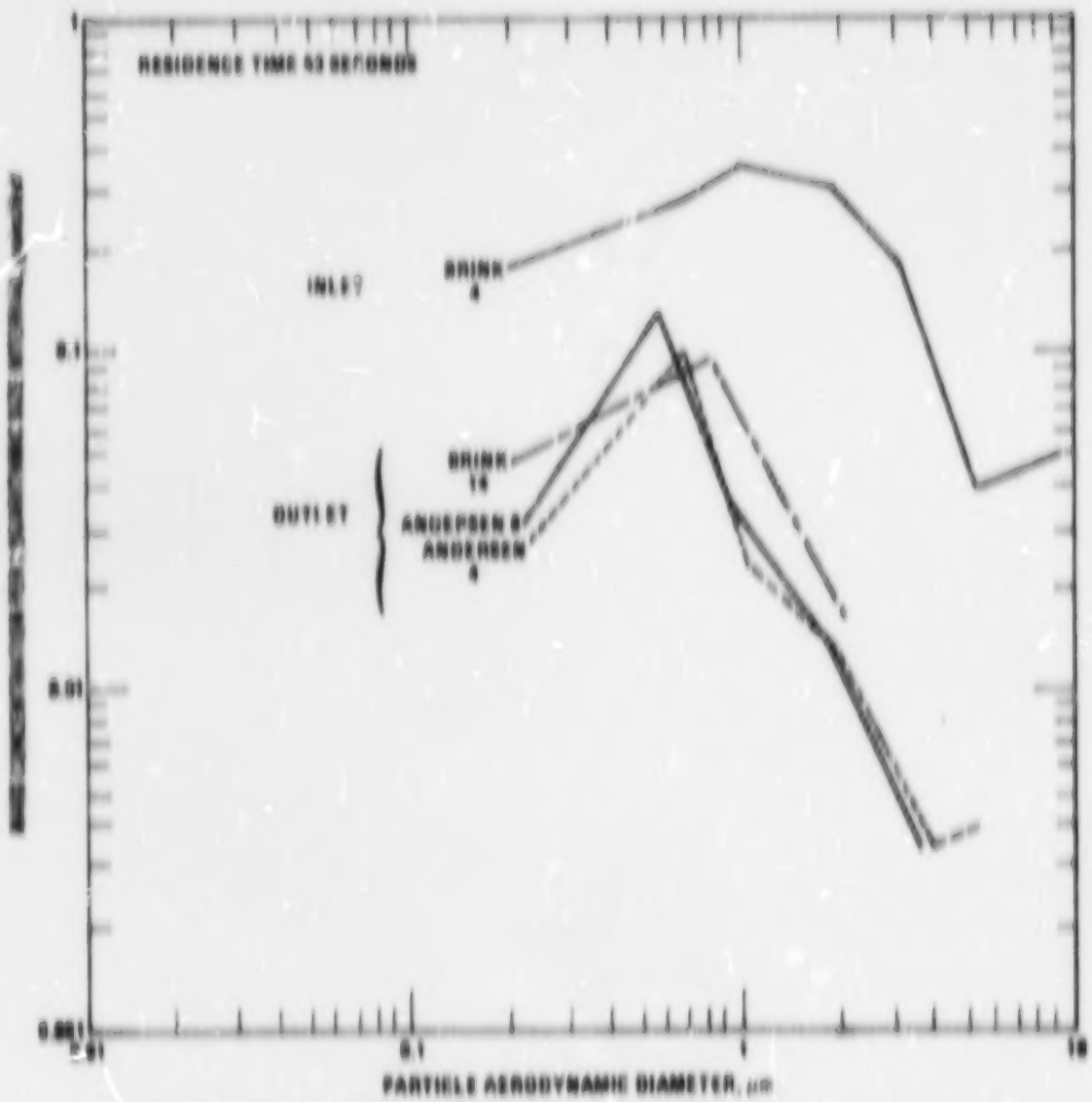

Figure 19. Inlet and outlet concentration distributions for 53 second residence time

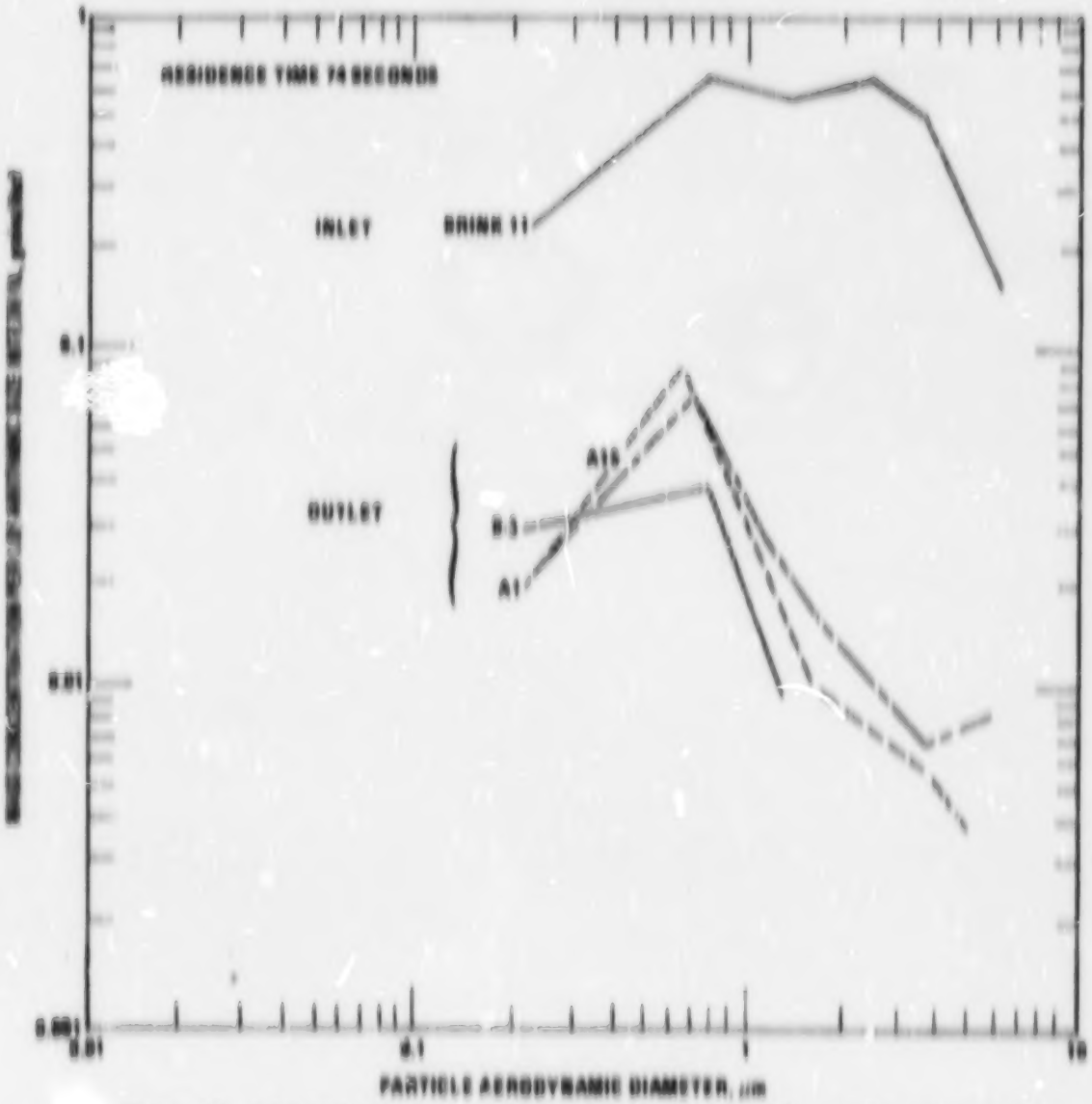

Figure 11. Inlet and outlet concentration distributions for 74 second residence time.

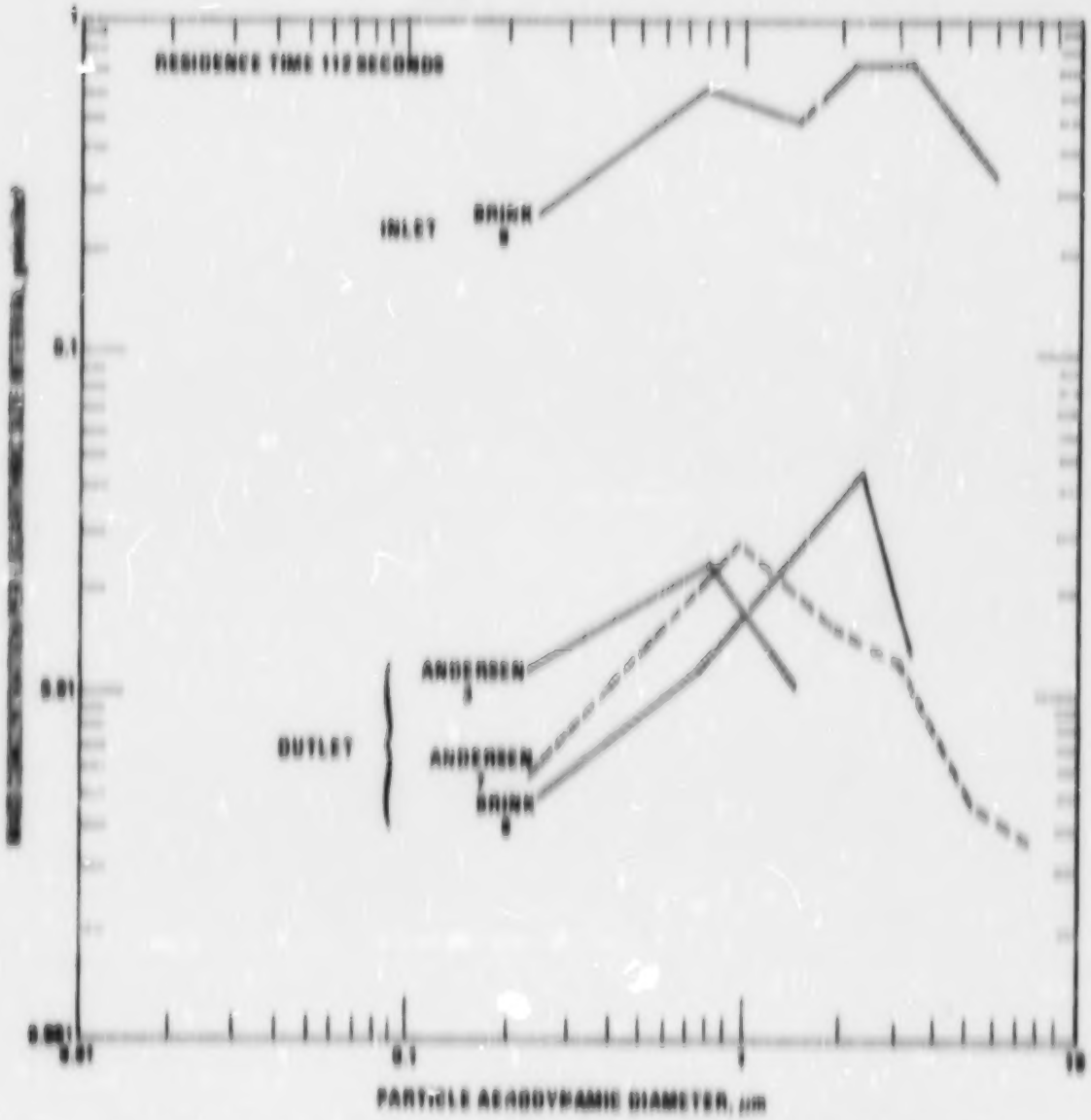

Figure 12. Inlet and outlet concentration distributions for 112 second residence time

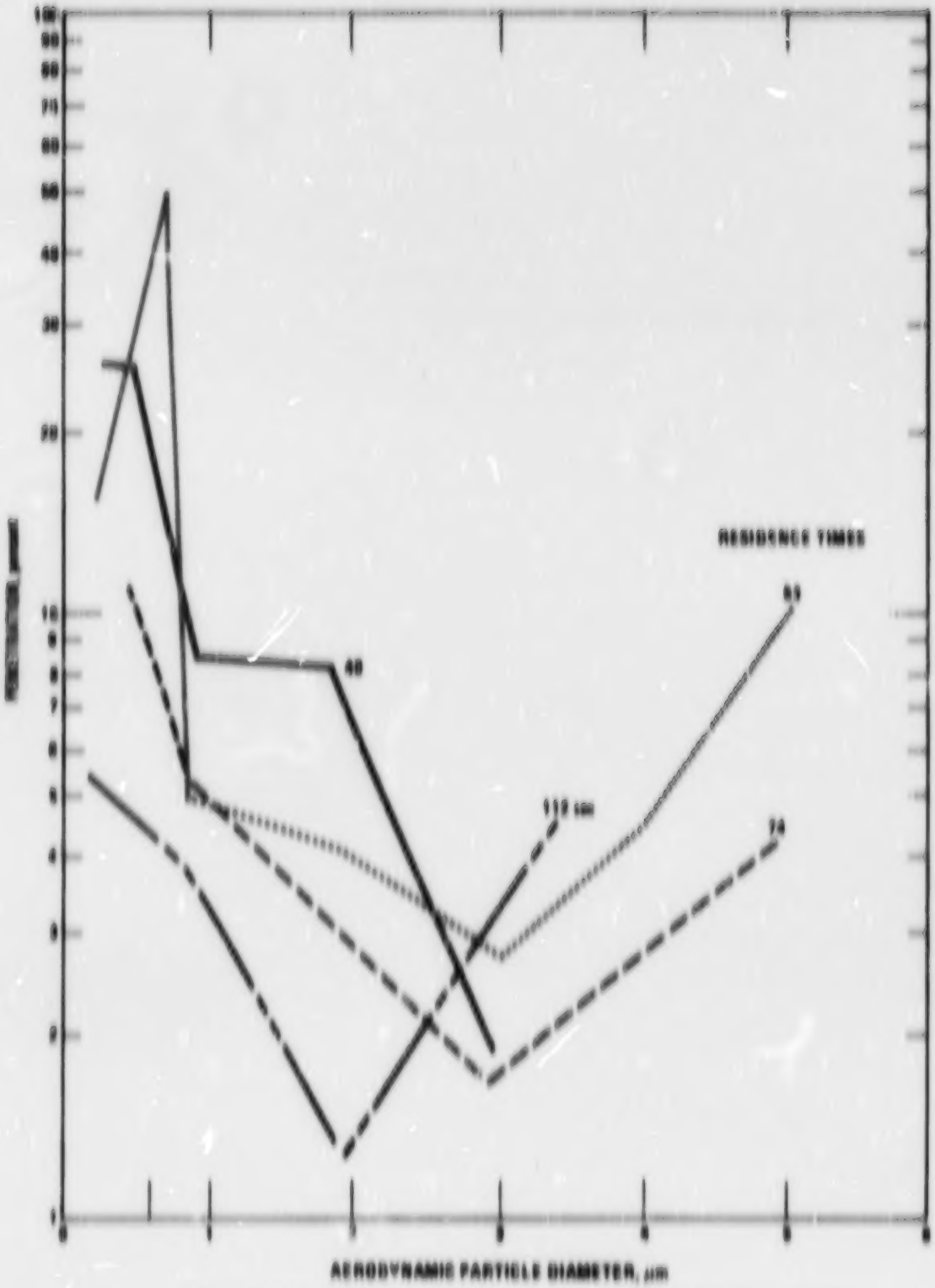

Figure 13. Penetration versus particle size for various residence times.

If the predominant collection mechanisms for foam scrubbing were sedimentation and interception, one would expect the penetration to decrease with increasing particle size. If diffusion were predominant, one would expect an improvement in collection efficiency at the smallest particle sizes. At last one more consideration must be made with foam scrubbing with no demister: some fraction of particulate material which has been captured in the foam will escape the destruction chamber, either because the droplets are too fine to be retained or because the liquid is atomized when impacted against the chamber walls.

Figure 13 shows that the efficiency decreases with increasing particle size for particles above 3 μm, so interception and sedimentation are not important in foam scrubbing and diffusion does appear to be the predominant collection mechanism. The increase in penetration for particles less than 3 μm, as shown in Figure 13, is probably a result of the entrainment problem. The entrainment problem due to foam destruction is discussed in Appendix C.

The curves in Figures 9 through 12 show that the outlet concentration for all particle sizes decreases as residence time increases. The curves for two different residence times cannot be compared exactly because each residence time has a different inlet concentration due to different air flows to the particle generator.

The outlet grain loadings calculated by the computer and based on the impactor data are plotted versus residence times in Figure 14. From this plot and the penetration curves of Figure 13, the outlet grain loading appears to reach a minimum at about 2 minutes.

A final test was run to determine the efficiency of the screen in removing particles from the gas stream. The test involved spraying only water onto the screen while the particulate laden air passed through so no foam was produced. All other conditions were the same as the tests with foam. The results of the test are shown in Figure 15 and the penetration is shown in Figure 16. Only the larger particles were removed at the screen; particles less than 1 micron were unaffected.

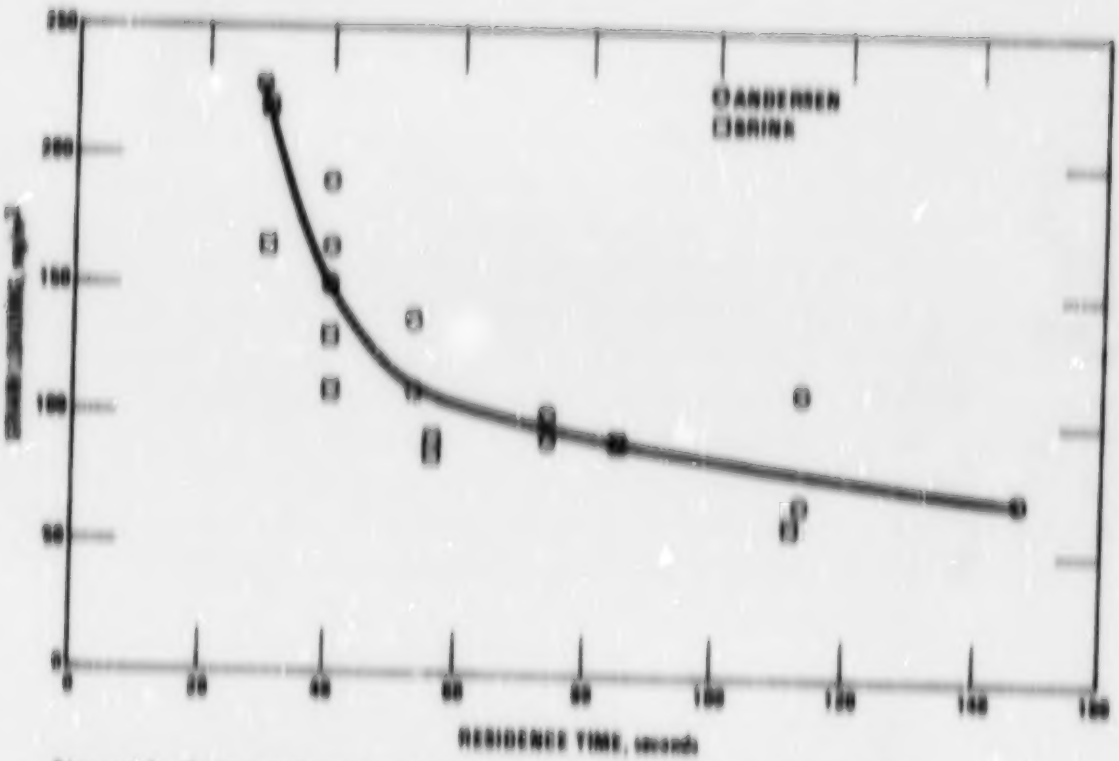

Figure 14. Grain loading of scrubber outlet versus residence time, based on impactor runs.

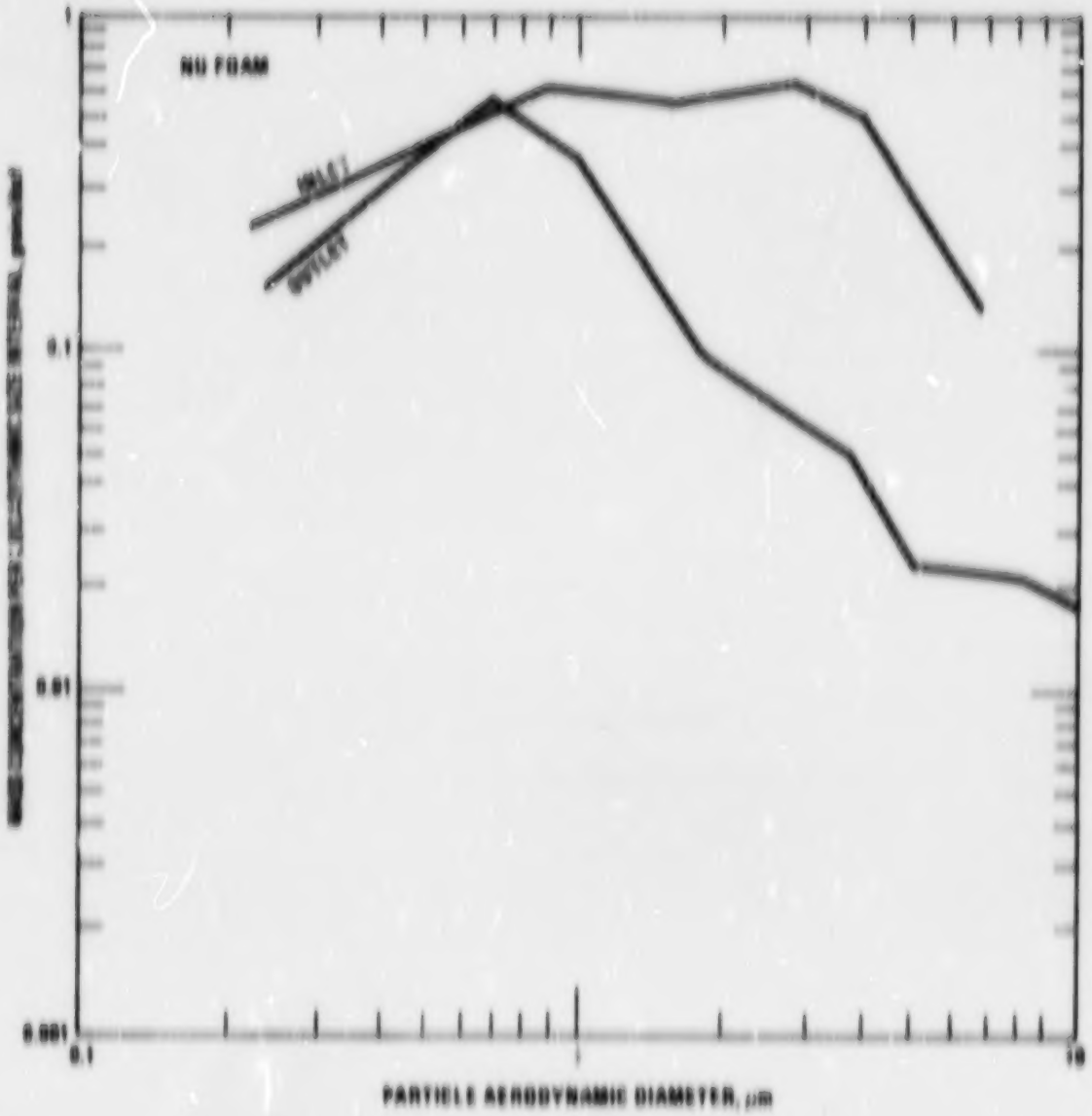

Figure 15. Inlet and outlet concentration distributions for water spray only.

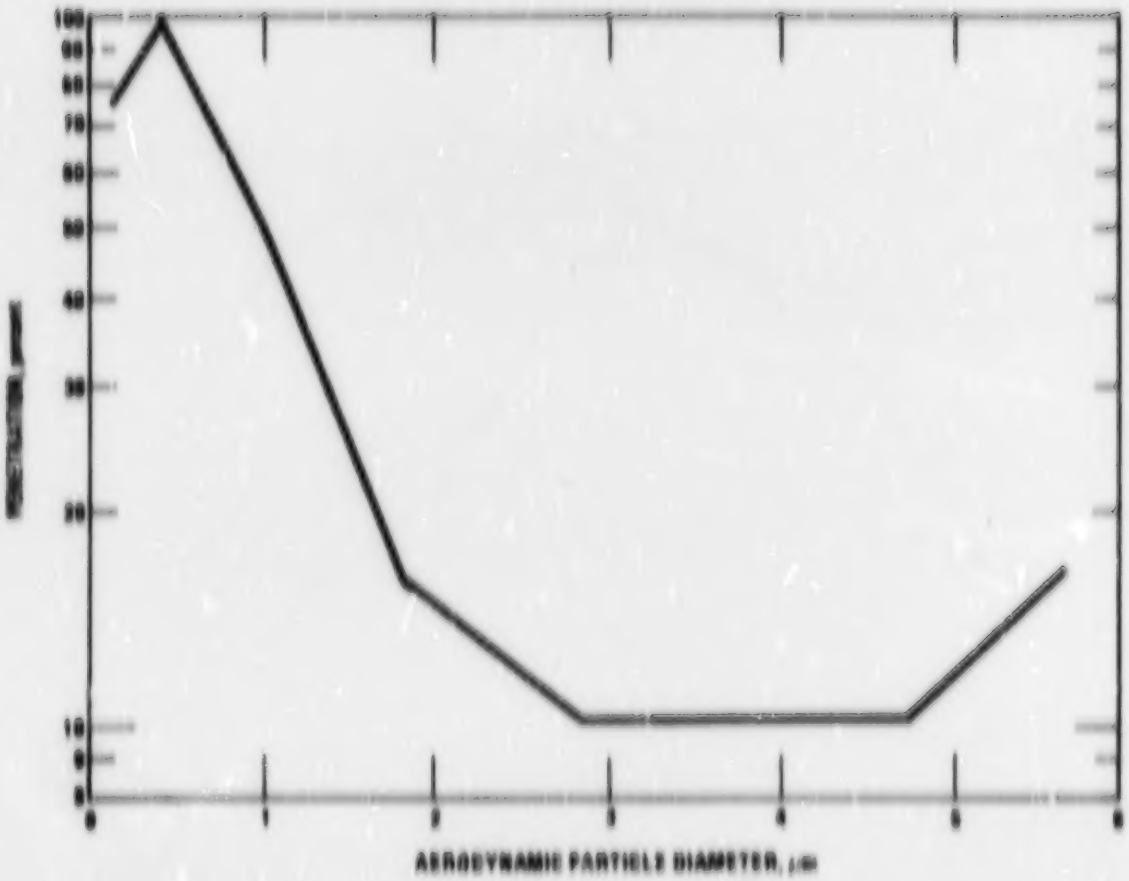

Figure 16. Penetration versus particle size for water spray test.

SECTION VI

FOAM SCRUBBER ECONOMICS

Based upon the data collected during this small scale investigation of foam scrubbing, a scale-up was attempted to determine the economic feasibility of foam scrubbing. Since this experiment was representative of very low flow rates and high residence times, the major limitation may be the size of the unit. Foam scrubbing has been compared to other conventional control devices; capital cost estimates indicate that foam scrubbing costs are similar to those for electrostatic precipitation, the most expensive conventional control method.[2]

The foam scrubber as tested had a maximum air flow of 6 cfm (0.17 m^3/min) through the 15.24 (6 inch) diameter duct. When scaling up the foam scrubber to much larger air flows, the size of the apparatus becomes unmanageably large. Table 2 shows the screen areas required for different flow sizes for foam scrubbers with an air velocity of 37 ft/min (11.28 m/min). The screen area at 1000 cfm (28.30 m^3/min) would be 26.6 ft^2 (2.47 m^2) which represents a rather large duct. Also shown in Table 2 is the foam volume required for a residence time of 2 minutes. The data from Table 2 tends to prove that, from the standpoint of total area and volume, foam scrubbing would not be attractive for large flow volumes.

The most costly expenditure in the operating cost for foam scrubbing is the cost of the surfactant. Using a less costly surfactant, increasing the recycle percentage, or reducing the liquid-to-air ratio at the screen can reduce the surfactant cost. At 99 percent surfactant recycle, the cost of the surfactant amounts to over 75% of the total operating cost as shown in Table 3. The operating cost for foam scrubbing is not dependent on residence time since the operating cost of the installed equipment is minimal compared to the cost of the surfactant. Comparison of foam scrubbing to conventional control devices, as presented in Figure 17, shows, that the operating cost of foam scrubbing with 99 percent surfactant recycle is an order of magnitude greater than the most expensive conventional control method (high energy wet scrubbing).[2]

Table 2. SCREEN AREAS AND LIQUID FLOW RATES FOR VARIOUS SIZE FOAM SCRUBBERS[a]

Flow Rate (cfm)	7.5	1000	10,000	100,000
Screen area (ft^2)	0.20	26.6	266	2660
Liquid spray rate (gpm)	0.25	33	330	3300
Make-up surfactant at 99% recycle (gpm)	0.002	0.198	1.98	19.8
Volume of foam required for 2 min residence time (gal.)	112	15,000	150,000	1,500,000
Volume of foam required for 1 min residence time (gal.)	56	7,500	75,000	750,000

[a]At scrubber air velocity of 37 ft/min

Table 3. OPERATING COST FOR 50,000 ACFM SCRUBBER AT 99% RECYCLE

	Percent of Total		$/acfm
Labor	7		1.60
Materials			
Surfactant	76		17.08
Other	1		0.45
Utilities	13		2.93
Depreciation	1		0.23
Capital Charges	2		0.45
		Total	22.72

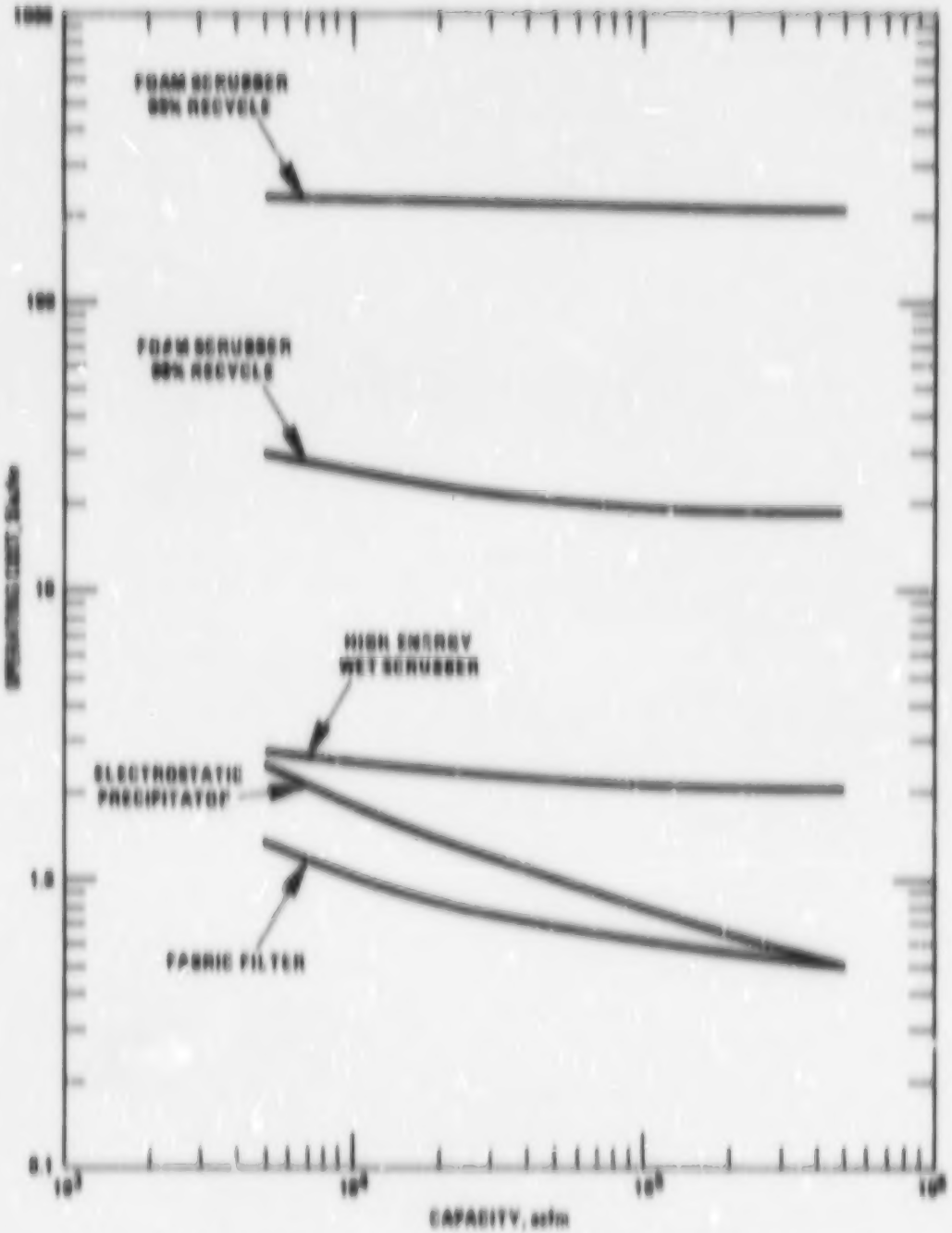

Figure 17. Comparison of various control devices for fine particle control.

SECTION VII

REFERENCES

1. Calvert, Seymour, Jhuda Goldshmid, David Leith, and Dilip Mehta. "Wet Scrubber Systems Study, Scrubber Handbook," A. P. T., Inc.; EPA-R2-72-118a (NTIS No. PB 213016), August 1972.

2. Ctvrtnicek, T. E., C. M. Muscowitz, T. F. Walburg, and H.H.S. Yu. "Application of Foam Scrubbing to Fine Particle Control, Phase I," Monsanto Research Corporation, EPA-600/2-76-125 (NTIS No. PB 261075/AS), May 1976.

3. Smith, W. B., K. M. Cushing, and J. D. McCain. "Particulate Sizing Techniques for Cont[illegible] Device Evaluation," Southern Research Institute, EPA-650/2-74-102 (NTIS No. PB 240670/AS), October 1974.

APPENDIX A

THE METALLIZING SPRAY GUN AS A FINE PARTICULATE GENERATOR

Preliminary experiments were run with the Wall Colmonoy Model VT-500 metallizing spray gun to determine the conditions necessary to generate a satisfactory particulate to be tested on the foam scrubber. The metallizing spray gun generated fine particles by melting two metal wires with an electric arc. The metal wires were fed continuously by the spray gun and a compressed air stream was directed through the arc zone to atomize the molten metal and propel the particles to the foam scrubber. The spray was directed into a 55 gallon (208l) drum to allow the larger particles to settle to the bottom. The drum and spray system is shown in Figures A1 and A2.

Actually very few of the particles settled in the drum because the metal particles were impacted on the side of the drum opposite the wire and compressed air entry point forming a very heavy layer of metal on the side of the drum. The compressed air through the arc zone, which was the only source of air to generate foam, probably was too high and caused the metal buildup. A longer spray length probably would have decreased the buildup and increased the grain loading of the stream out of the drum.

A sample of the particles generated from the carbon steel wire was analyzed by X-ray diffraction and found to be gamma Fe_2O_3. The corresponding layer of metal on the side of the drum was analyzed by X-ray fluorescence and found to be essentially metallic iron.

A complete set of impactor runs were made with the metallizing spray gun to determine the effect of air flow, voltage, and wire feed rate on the size and number of particles generated using carbon steel wire. The experimental conditions are given in Table A1. The particle characteristics for each of the tests were determined, using the Brink cascade impactor. The sample was collected isokinetically at the inlet sampling port of the foam scrubber. The same sampling conditions were utilized for the particle generation tests as for the foam scrubber inlet tests. The distribution curves for the voltage, air flow, and wire feed rate (in Figures A3, A4, and A5) resulted in an increase in

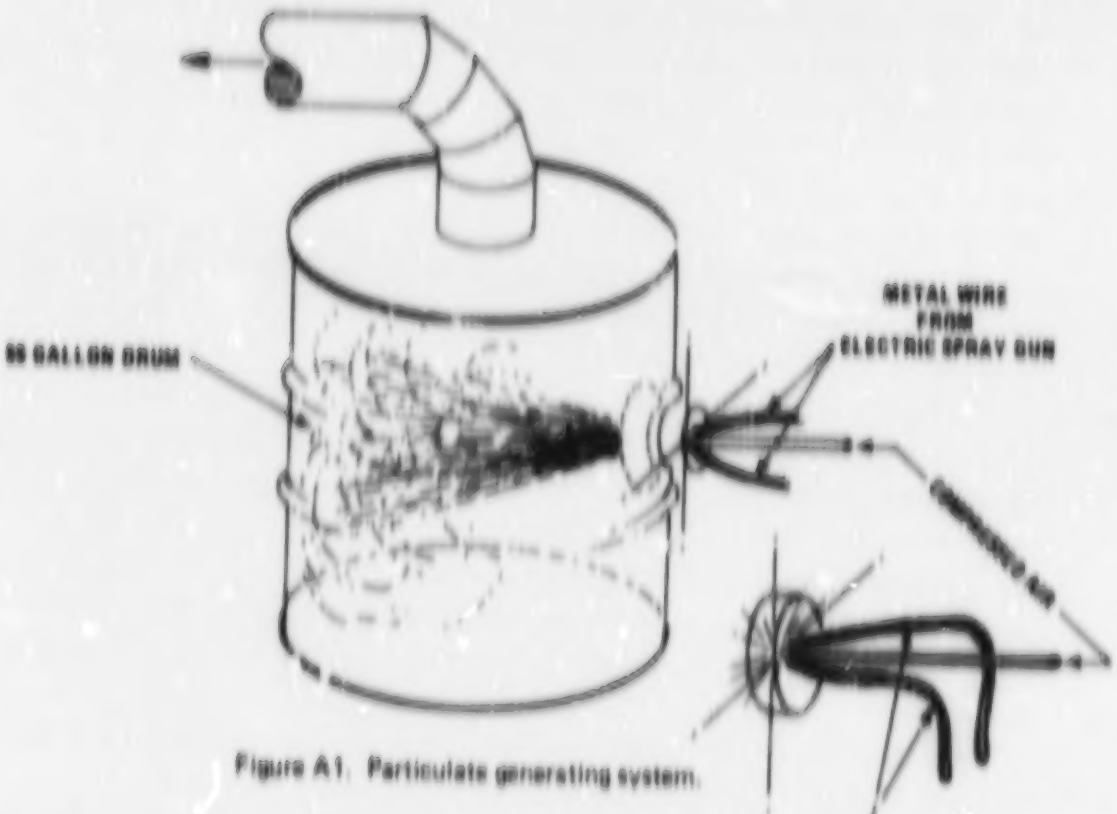

Figure A1. Particulate generating system.

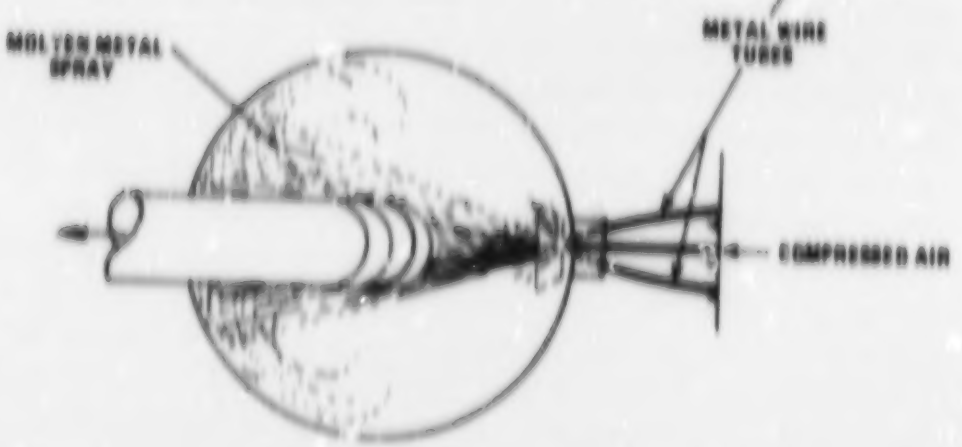

Figure A2. Top view of electric arc area.

Table A1. EXPERIMENTAL CONDITIONS FOR WIRE SPRAY GUN TESTS FOR IRON OXIDE

Air Flow, cfm	Pressure, psi	Voltage	Carbon Steel Wire Feed Rate, lb/min
4.4	10	25	0.0224
4.4	10	28	0.0224
4.4	10	31	0.0224
4.4	10	25	0.0706
4.4	10	28	0.0706
4.4	10	31	0.0706
4.4	10	25	0.1272
4.4	10	28	0.1272
4.4	10	31	0.1272
6.3	20	25	0.0224
6.3	20	28	0.0224
6.3	20	31	0.0224
6.3	20	25	0.0706
6.3	20	28	0.0706
6.3	20	31	0.0706
6.3	20	25	0.1272
6.3	20	28	0.1272
6.3	20	31	0.1272
8.8	30	25	0.0224
8.8	30	28	0.0224
8.8	30	31	0.0224
8.8	30	25	0.0706
8.8	30	28	0.0706
8.8	30	31	0.0706
8.8	30	25	0.1272
8.8	30	28	0.1272
8.8	30	31	0.1272

the mean particle size--and to a minor extent, increasing the voltage increased the mean particle size. The same results are obtained by plotting voltage, air flow, and wire feed rate versus grain loadings as seen in Figures A6, A7, and A8.

A second set of tests were run with the aluminum wire in which the voltage was varied from 22 to 46 volts with all other conditions constant. For comparison five runs were made with the carbon steel wire for voltages from 34 to 46 volts. The impactor samples were collected under the same conditions as described previously; results are given in Table A2. As the voltage increased, the grain loading increased with a higher percentage of large particles in the sample.

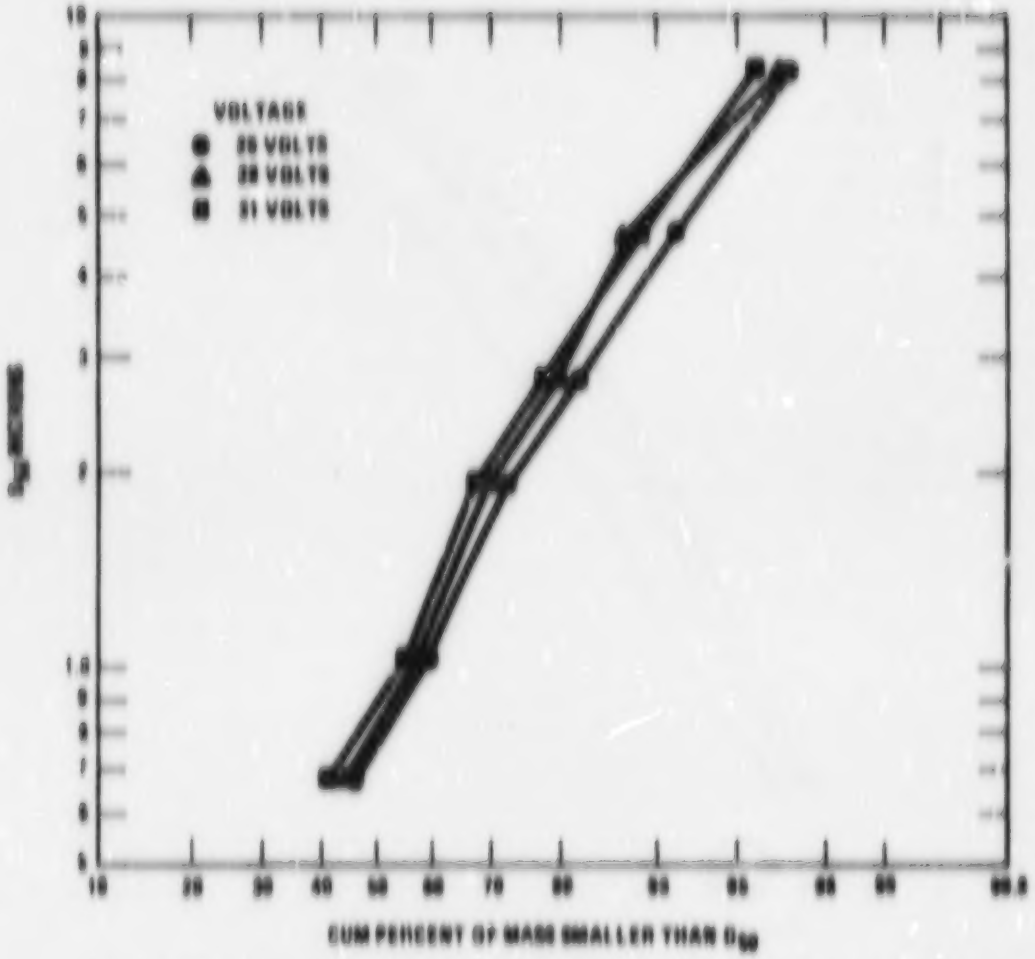

Figure A3. Distribution curves for metallizing spray gun tests based on voltages.

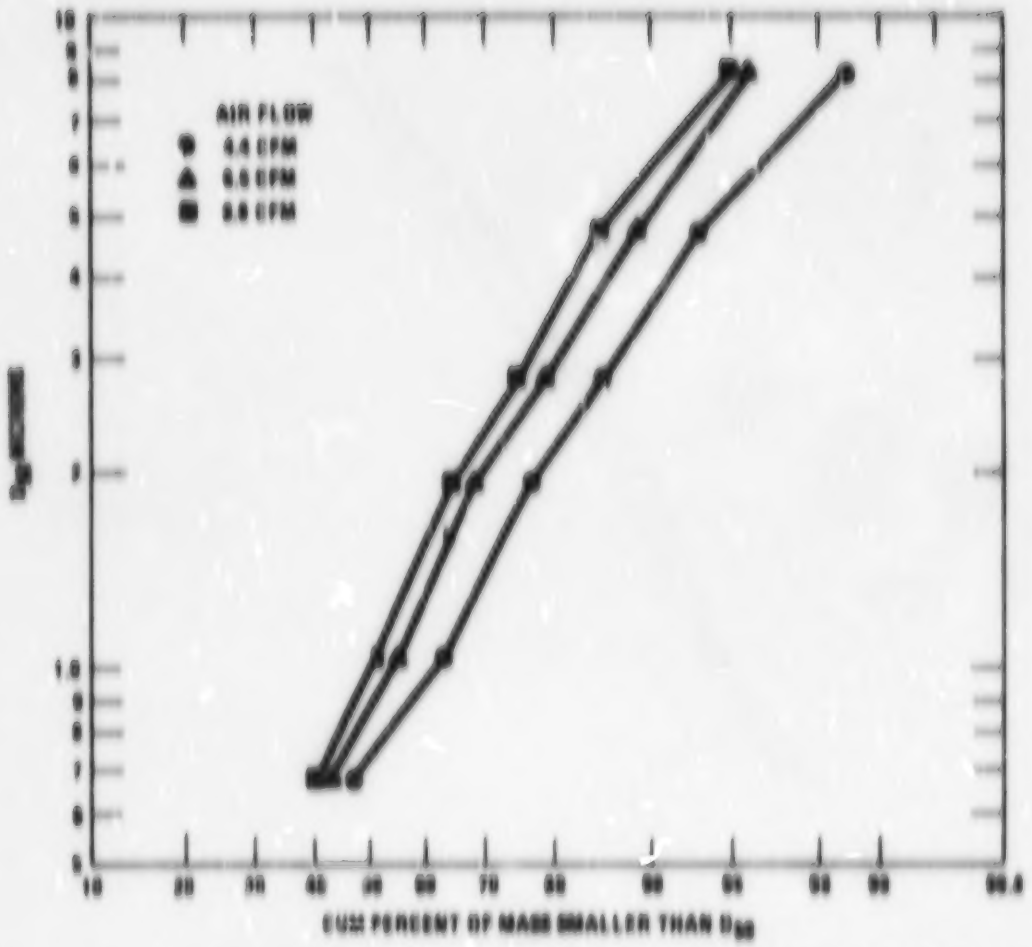

Figure A4. Distribution curves for metallizing spray gun tests based on air flow rates.

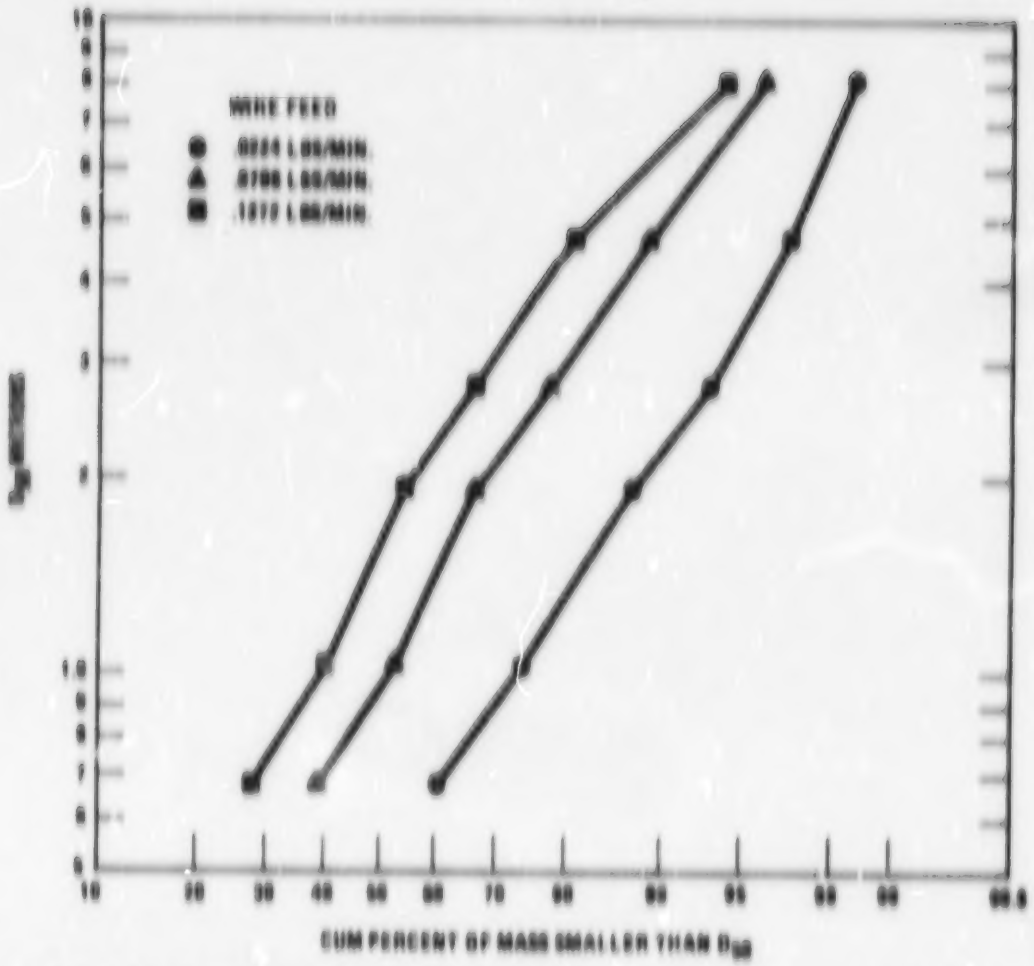

Figure A8. Distribution curves for metallizing spray gun tests based on wire feed rate.

Figure A6. Outlet grain loading versus voltage for iron oxide.

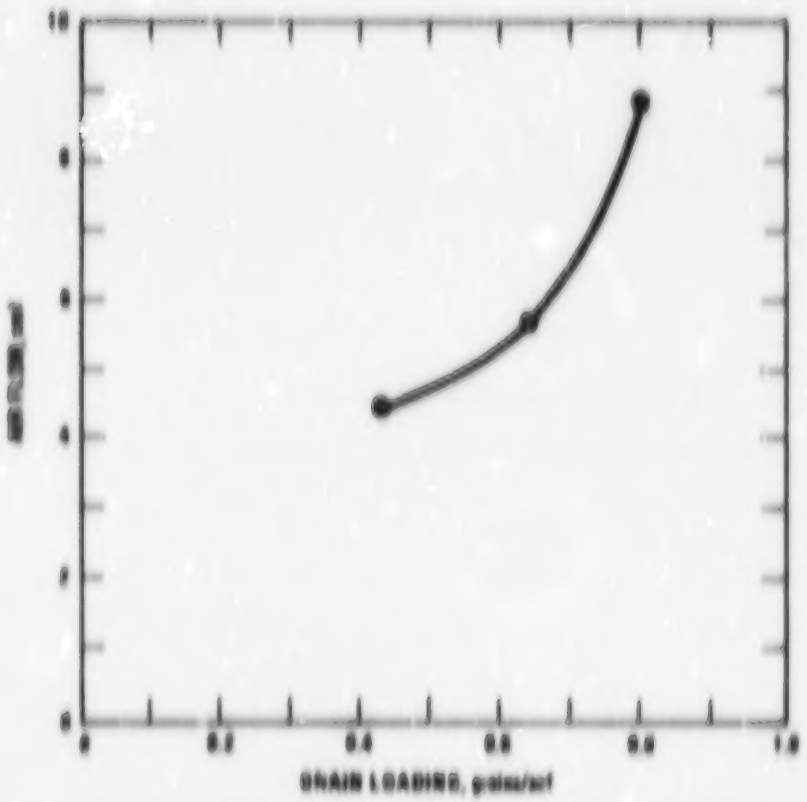

Figure A7. Outlet grain loading versus air flow for iron oxide.

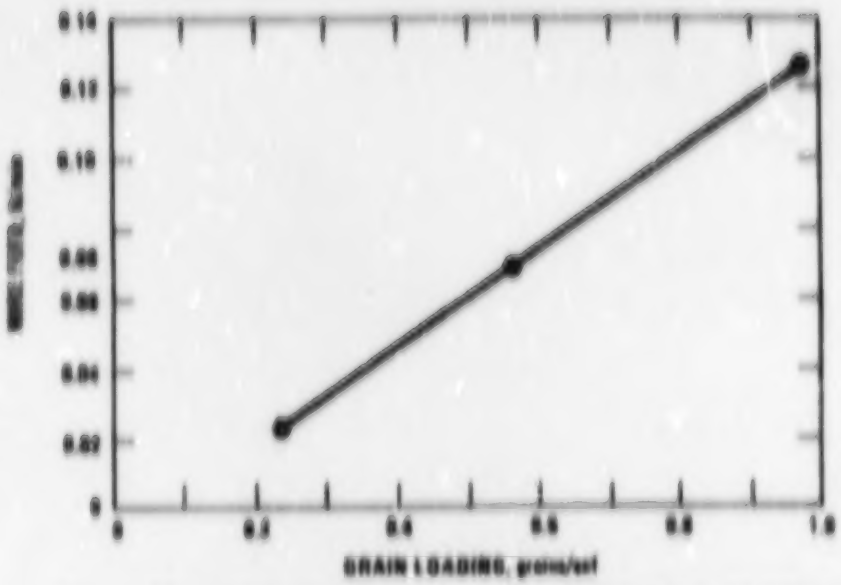

Figure A8. Outlet grain loading versus wire feed rate for iron oxide.

Table A2. TEST DATA FOR ALUMINUM OXIDE AND IRON OXIDE FOR VARIOUS [illegible][a]

Voltage	Grain Loading grains/acf	Percent Less Than Stated Size						
		13.5 μ	8.2 μ	4.7 μ	2.8 μ	1.6 μ	1.0 μ	0.7 μ
	Aluminum Oxide[b]							
22	0.756	100	97.19	85.92	73.24	61.98	49.38	35.77
25	1.032	100	92.10	71.19	60.37	54.83	47.46	35.60
28	1.646	78.58	77.24	64.74	48.67	38.84	31.26	23.67
31	1.631	64.29	57.15	51.79	39.29	35.91	27.39	20.24
34	1.667	60.19	59.26	52.56	47.23	51.67	31.49	26.71
37	3.676	75.20	70.23	59.55	47.71	33.27	19.47	11.84
40	2.861	64.10	59.83	51.34	41.97	32.15	21.80	13.40
43	2.637	74.15	64.88	57.08	47.32	37.08	24.40	16.59
46	2.876	68.95	65.30	57.08	46.12	35.62	23.75	15.53
	Iron Oxide[c]							
34	1.942	80.80	77.49	68.88	43.71	34.44	26.92	19.21
37	1.659	80.63	75.97	67.45	57.37	45.74	34.80	23.16
40	2.148	81.44	76.85	65.27	51.50	37.73	27.55	19.57
43	1.298	79.21	72.28	58.41	47.53	31.67	26.74	21.79
46	2.680	55.98	52.64	43.07	31.58	23.45	18.67	18.85

[a]For all tests, spray pressure was 20 psi and air flow was 6.3 cfm.

[b]Wire feed rate was 6.2 gal/min.

[c]Wire feed rate was 60 gal/min.

APPENDIX B

ANDERSEN AND BRINK IMPACTOR DATA

ANDERSEN IMPACTOR

Date 6/7/76 Run # 4-1

Sample volume at STP (ft^3) = 2.362

Impactor flow rate (acfm) = 0.472

Concentration (grains/ft^3) = 0.0444

Location outlet

Bar. Pressure (in Hg) 30.13

Temp in duct (°F) = 75.0

Time (minutes) = 5.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% of stated size	dm/d log D	Geo. Mean (μm)
1	.0000		13.87	100.00	.0000	16.65
2	.0000		9.76	100.00	.0000	11.63
3	.0000		6.05	100.00	.0085	7.67
4	.0002	2.34	4.24	97.06	.0071	5.07
5	.0002	2.34	2.79	94.12	.0113	3.45
6	.0004	8.82	1.52	85.30	.0277	1.92
7	.0003	13.24	0.82	72.06	.0713	1.04
8	.0014	20.59	0.61	51.48	.0257	0.70
F	.0035	51.47				0.22
Total	.0068					

Residence Time 74 sec

Air Flow 4.0 cfm

ANDERSEN IMPACTOR

Date 6/7/76 Run # A-2 Location outlet

Sample volume at STP (ft^3)	= 4.027	Bar. Pressure (in Hg)	30.13
Impactor flow rate (acfm)	= 0.503	Temp in duct (°F)	= 75
Concentration (grains/ft^3)	= 0.0738	Time (minutes)	= 8

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% of stated size	dm/d log D	Geo. Mean (μm)
1	.0000		13.44	100.00		16.39
2	.0000		9.45	100.00		11.27
3	.0002	1.05	5.84	28.35	.0036	7.43
4	.0003	1.58	4.13	27.37	.0075	4.91
5	.0005	1.58	2.70	25.79	.0062	3.39
6	.0015	6.84	1.28	80.95	.0151	1.86
7	.0020	10.53	0.79	78.43	.0360	1.00
8	.0062	32.63	0.59	45.79	.1847	0.68
F	.0087	45.79			.0381	0.21
Total	.0190					

Residence time = 40 sec.
Air flow = 7.4 cfm

ANDERSEN IMPACTOR

Date 6-8-76 Run # A-3 Location Outlet

Sample volume at STP (ft^3) = 2.70 Bar. Pressure (in Hg) = 30.13

Impactor flow rate (a.fm) = 0.542 Temp in duct (°F) = 75.0

Concentration (grains/ft^3) = 0.0296 Time (minutes) = 5.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% of stated size	dm/d log D	Geo. Mean (μm)
1						
2						
3						
4						
5			2.61	100.00		3.22
6	.0005	9.62	1.23	90.39	.0084	1.79
7	.0008	15.38	.76	75.00	.0214	0.96
8	.0016	30.85	.56	44.14	.0642	0.66
F	.0024	46.15			.0160	0.21
Total	.0052					

Residence Time = 113 sec.

Air Flow = 2.6 cfm

ANDERSEN IMPACTOR

Date 6-8-76 Run # A-4 Location outlet

Sample volume at STP (ft^3) = 2.494 Bar. Pressure (in Hg) 30.38

Impactor flow rate (acfm) = 0.439 Temp in duct (°F) = 76.0

Concentration (grains/ft^3) = 0.0185 Time (minutes) = 5.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
1						
2						
3			5.87	100.00		7.46
4	.0001	1.28	9.14	38.72	.0042	4.93
5	.0001	1.28	2.72	37.44	.0033	3.35
6	.0007	8.97	1.28	28.47	.0131	1.87
7	.0009	11.54	0.79	76.93	.0261	1.01
8	.0021	16.92	0.53	30.01	.0985	0.68
F	.0039	50.00			.0274	0.21
Total	.0078					

Residence Time 53 sec.

Air Flow 5.5 cfm

ANDERSEN IMPACTOR

Date 6-10-76 Run # A-6 *
Sample volume at STP (ft^3) = 5.00
Impactor flow rate (acfm) = 0.599
Concentration (grains/ft^3) = 0.0664

Location outlet
Bar. Pressure (in Hg) 30.22
Temp in duct (°F) = 75
Time (minutes) = 5

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% stated size	dm/d log D	Geo. Mean (μm)
1						
2						
3						
A			5.78	100.00		4.49
5	.0005	3.88	2.47	36.13	.0138	3.06
6	.0014	10.85	1.17	85.28	.0218	1.69
7	.0022	17.05	0.72	68.22	.0528	0.91
8	.0035	27.13	0.33	41.09	.1351	0.41
9	.0053	41.09			.0528	0.20
Total	.0129					

Residence Time = 40 sec.
Air Flow = 8.3 cfm

* Runs # A-5, A-13, A-14, B-1, B-2, B-7, B-13, and B-15 are not included because of equipment malfunction during the tests. Either the particle generator or the foam destructor malfunctioned causing the tests to be voided.

ANDERSEN IMPACTOR

Date 6-10-74 Run # A-7 Location Outlet

Sample volume at STP (ft^3) = 1.99 Bar. Pressure (in Hg) 30.22

Impactor flow rate (acfm) = 0.498 Temp in duct (°F) 75

Concentration (grains/ft^3) = 0.0088 Time (minutes) = 4.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% of stated size	dm/d log D	Geo. Mean (μm)
1						
2			9.50	100.00		11.33
3	.0001	5.05	5.80	76.27	.0037	7.47
4	.0001	5.05	4.15	53.24	.0031	4.24
5	.0003	9.09	2.72	34.85	.0125	3.36
6	.0004	18.18	1.29	16.67	.0141	1.87
7	.0007	21.21	0.79	4.96	.0256	1.01
8	.0008	24.24	0.59	21.22	.0123	0.68
F	.0007	21.21			.0062	0.21
total	.0033					

Residence Time = 113 sec.

Air Flow = 2.6 cfm

ANDERSEN IMPACTOR

Date 6-11-76 Run # A-B
Sample volume at STP (ft^3) = 2.90
Impactor flow rate (acfm) = 0.80
Concentration (grains/ft^3) = 0.0605

Location outlet
Bar. Pressure (in Hg) 29.95
Temp in duct (°F) = 75.0
Time (minutes) = 5.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
1						
2						
3						
A			4.14	100.00		4.32
B	.0001	1.02	2.71	98.98	.0033	3.35
C	.0009	9.18	1.28	89.80	.0170	1.81
D	.0012	12.24	0.79	77.56	.0350	1.01
E	.0028	28.57	0.53	48.98	.1356	0.68
F	.0048	48.98			.0340	0.21
Total	.0098					

Residence Time = 55 sec.
Air Flow = 5.5 cfm

ANDERSEN IMPACTOR

Date 6-14-76 Run # A-9 Location outlet

Sample volume at STP (ft^3) = 2.48 Bar. Pressure (in Hg) = 30.07

Impactor flow rate (acfm) = 0.496 Temp in duct (°F) = 75.0

Concentration (grains/ft^3) = 0.0096 Time (minutes) = 5.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% stated size	dm/d log D	Geo. Mean (μm)
1			15.54			14.96
2	.0000		9.52	100.00		11.36
3	.0001	0.63	5.82	99.38	.0050	7.49
4	.0003	1.88	4.11	97.50	.0125	4.35
5	.0004	2.50	2.73	95.01	.0135	3.37
6	.0009	5.63	1.29	89.38	.0171	1.87
7	.0022	13.75	0.79	75.63	.0496	1.01
8	.0035	21.87	0.59	53.76	.1492	0.68
F	.0086	53.75			.0611	0.22
Total	.0160					

Residence Time = 2.9 sec.

Air Flow = 10 cfm

ANDERSEN IMPACTOR

Date 6-14-76 Run # A-10
Sample volume at STP (ft^3) = 2.47
Impactor flow rate (acfm) = 0.494
Concentration (grains/ft^3) = 0.028

Location outlet
Bar. Pressure (in Hg) 30.07
Temp in duct (°F) = 75.0
Time (minutes) = 5.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% stated size	dm/d log D	Geo. Mean (μm)
1						
2						
3			5.90			7.50
4	.0000	0.00	4.17	100.00		4.96
5	.0001	2.52	2.73	97.78	.0034	3.37
6	.0005	11.11	1.29	86.67	.0095	1.88
7	.0004	13.33	0.80	73.34	.0177	1.01
8	.0012	26.67	0.39	46.67	.0382	0.63
F	.0021	46.67			.0150	0.22
Total	.0045					

Residence Time = 147 sec.
Air Flow 2.0 afm

ANDERSEN IMPACTOR

Date 6-15-76 Run # A-11 Location Outlet

Sample volume at STP (ft^3) = 1.571 Bar. Pressure (in Hg) 29.91

Impactor flow rate (acfm) = 0.524 Temp in duct (°F) = 75.0

Concentration (grains/ft^3) = 0.1150 Time (minutes) = 3.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% of stated size	dm/d log D	Geo. Mean (μM)
1						
2						
3						
4	.0000	0.00	4.04	100.00		4.81
5	.0003	2.56	2.65	37.44	.0160	3.27
6	.0008	6.84	1.25	30.60	.0140	1.82
7	.0026	22.22	0.77	68.38	.1208	0.98
8	.0025	29.31	0.57	38.47	.2675	0.66
F	.0045	38.46			.0515	0.21
Total	.0117					

Residence Time = 74 sec.
Air Flow = 4.0 cfm

ANDERSEN IMPACTOR

Date 6-14-76 Run # A-12 Location Outlet

Sample volume at STP (ft^3) = 2.52 Bar. Pressure (in hg) 29.91

Impactor flow rate (acfm) = 0.305 Temp in duct (°F) = 75.0

Concentration (grains/ft^3) = 0.083 Time (minutes) = 8.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
1						
2						
3						
4	.0000	0.00	4.12	100.00		4.30
5	.0001	0.78	2.70	99.22	.0055	3.36
6	.0010	7.35	1.28	91.92	.0187	1.85
7	.0022	16.18	0.73	75.74	.0657	1.00
8	.0041	30.15	0.39	45.59	.1969	0.68
F	.0062	45.59			.0436	0.22
Total	.0136					

Residence Time = 40 sec

Air Flow = 7.4 acfm

ANDERSEN IMPACTOR

Date 6-21-76 Run # A-15 Location Outlet

Sample volume at STP (ft^3) = 2.86 Bar. Pressure (in Hg) 30.14

Impactor flow rate (acfm) = 0.571 Temp in dust (°F) = 75.0

Concentration (grains/ft^3) = 0.0405 Time (minutes) = 5.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% of stated size	dm/d log D	Geo. Mean (μm)
1						
2						
3	.0000		5.48	100.00		6.32
4	.0001	1.33	3.87	38.67	.0088	4.60
5	.0002	2.67	2.54	34.00	.0038	3.13
6	.0006	8.00	1.20	98.01	.0038	1.74
7	.0014	18.67	0.79	63.34	.0354	0.94
8	.0021	28.00	0.55	41.34	.0080	0.65
F	.0031	41.33			.0128	0.21
Total	.0075					

Residence Time = 74 sec.

Air Flow = 4.0 cfm

ANDERSEN IMPACTOR

Date 6-22-76 Run # A-15 Location Outlet

Sample volume at STP (ft^3) = 1.391 Bar. Pressure (in Hg) 30.14

Impactor flow rate (acfm) = 0.830 Temp in duct (°F) = 75.0

Concentration (grains/ft^3) = 0.350 Time (minutes) = 5.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
1	.0005	0.88	13.09	99.13	.0154	16.18
2	.0005	0.88	9.20	98.25	.0188	10.78
3	.0005	1.47	5.69	96.78	.0250	7.24
4	.0004	1.17	4.02	95.61	.0254	4.78
5	.0010	2.93	2.65	92.67	.0523	3.25
6	.0034	3.97	1.24	82.70	.1001	1.81
7	.0077	22.58	0.77	60.12	.3506	0.98
8	.0089	26.10	0.57	34.02	.6589	0.66
F	.0116	34.02			.1307	0.21
Total	.0341					

Water Spray only
Air Flow = 4.0 cfm

BRINK IMPACTOR

Date 5-24-76 Run # B-3 Location Outlet

Sample volume at STP (ft^3) = 0.655 Bar. Pressure (in Hg) = 29.80

Impactor flow rate (acfm) = 0.063 Temp in dust (°F) = 80.0

Concentration (grains/ft^3) = 0.039 Time (min) = 10.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	N.S. stated size	dm/d log D	Geo. Mean (μm)
Cyclone						
0						
1						
2						3.34
3	.0000	0.00	1.78	100.00	.0092	2.19
4	.0001	6.25	0.36	93.75	.0401	1.30
5	.0003	18.75	0.63	75.00	.0352	0.77
Filter	.0012	75.00				0.22
Total	.0016					

Residence Time = 85 sec.

BRINK IMPACTOR

Date 5-24-76 Run # B-4
Sample volume at STP (ft^3) = 0.150
Impactor flow rate (acfm) = 0.078
Concentration (grains/ft^3) = 0.391

Location Inlet
Bar. Pressure (in Hg) = 29.80
Temp in duct (°F) = 86.0
Time (min) = 2.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	D.* stated size	dm/d log D	Geo. Mean (μm)
Cyclone			11.53	100.00	.0000	15.16
0	.0001	2.63	7.01	77.37	.0485	8.99
1	.0001	2.63	3.38	34.73	.0427	5.28
2	.0004	10.53	2.17	84.22	.1855	3.07
3	.0005	13.16	1.63	71.06	.3226	1.96
4	.0009	23.68	0.88	47.37	.3500	1.19
5	.0005	13.16	0.57	39.22	.3804	0.71
Filter	.0013	34.21			.1539	0.21
Total	.0038					

BRINK IMPACTOR

Date 5-25-76 Run # B-5 Location Inlet

Sample volume at STP (ft^3) = 0.134 Bar. Pressure (in Hg) = 28.89

Impactor flow rate (acfm) = 0.067 Temp in duct (°F) = 86.0

Concentration (grains/ft^3) = 0.458 Time (min) = 2.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% stated size	dm/d log D	Geo. Mean (μm)
Cyclone						
0			7.42	100.00	.0000	9.51
1	.0005	13.16	4.22	86.85	.2386	5.60
2	.0003	7.89	2.51	78.95	.1555	3.25
3	.0007	18.42	1.73	60.53	.5051	2.08
4	.0003	7.89	0.93	52.64	.1304	1.27
5	.0003	7.89	0.61	44.74	.1890	0.75
Filter	.0017	44.74			.2261	0.22
Total	.0038					

BRINK IMPACTOR

Date 5-23-76 Run # B-6 Location outlet

Sample volume at STP (ft^3) = 0.576 Bar. Pressure (in Hg) = 29.77

Impactor flow rate (acfm) = 0.058 Temp in duct (°F) = 80.0

Concentration (grains/ft^3) = 0.057 Time (min) = 10.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	R.* stated size	dm/d log D	Geo. Mean (μm)
Cyclone 0						
1	.0000		9.57	100.00	.0000	6.05
2	.0001	4.76	2.72	35.24	.0121	3.52
3	.0003	14.28	1.87	80.96	.0308	2.26
4	.0004	19.05	1.01	61.91	.0402	1.38
5	.0005	23.81	0.66	38.10	.0742	0.82
Filter	.0008	38.10			.0138	0.29
Total	.0021					

Residence Time = 40 sec.

BRINK IMPACTOR

Date 6-27-76 Run # B-6
Sample volume at STP (ft^3) = 0.607
Impactor flow rate (acfm) = 0.61
Concentration (grains/ft^3) = 0.0257

Location outlet
Bar. Pressure (in Hg) = 30.15
Temp in duct (°F) = 80.0
Time (min) = 10.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	S.C. stated size	dm/d log D	Geo. Mean (μm)
Cyclone 0						
1	.0000		4.43	100.00	.0000	5.90
2	.0001	10.00	2.63	30.00	.0114	3.43
3	.0003	30.00	1.82	60.00	.0476	2.19
4	.0003	30.00	0.99	30.00	.0180	1.34
5	.0001	10.00	0.64	20.00	.0159	0.80
Filter	.0002	20.00			.0057	0.23
Total	.0010					

Residence Time 112 sec.

BRINK IMPACTOR

Date 5-28-76 Run # B-9 Location Inlet

Sample volume at STP (ft^3) = 0.118 Bar. Pressure (in Hg) = 30.10

Impactor flow rate (acfm) = 0.059 Temp in duct (°F) = 86.0

Concentration (grains/ft^3) = 0.890 Time (min) = 2.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	50% stated size	dm/d log D	Geo. Mean (μm)
Cyclone						
0	.0000		7.92	100.00	.0000	10.14
1	.0006	3.23	4.50	30.77	.3230	5.97
2	.0013	20.00	2.68	70.77	.7611	3.47
3	.0009	13.85	1.85	56.93	.7340	2.22
4	.0010	15.38	1.00	41.54	.4929	1.36
5	.0009	13.85	0.65	27.70	.6427	0.81
Filter	.0018	27.69			.2608	0.23
Total	.0065					

BRINK IMPACTOR

Date 5-28-74 Run # B-10 Location Inlet
Sample volume at STP (ft^3) = 0.109 Bar. Pressure (in Hg) = 30.16
Impactor flow rate (acfm) = 0.054 Temp in duct (°F) = 89.0
Concentration (grains/ft^3) = 0.643 Time (min) = 2.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% stated size	dm/d log D	Geo. Mean (μm)
Cyclone						
0	.0000		8.28	100.00	.0000	10.60
1	.0004	8.89	4.71	91.12	.3359	6.24
2	.0011	24.44	2.80	66.67	.7042	3.63
3	.0007	15.56	1.93	51.12	.6264	2.33
4	.0010	22.22	1.04	28.89	.5392	1.42
5	.0006	13.33	0.68	15.56	.4679	0.84
Filter	.0007	15.56			.1084	0.25
Total	.0045					

BRINK IMPACTOR

Date 5-28-76 Run # B-11
Sample volume at STP (ft^3) = 0.121
Impactor flow rate (acfm) = 0.060
Concentration (grains/ft^3) = 0.755

Location Inlet
Bar. Pressure (in Hg) = 30.07
Temp in duct (°F) = 89.0
Time (min) = 2.0

Stage	Net weight (gm)	% on stage	Stage cutoff (μm)	% stated size	dm/d log D	Geo. Mean (μm)
Cyclone						
0			7.85	100.00	.0000	10.06
1	.0003	5.26	4.46	34.74	.1590	6.31
2	.0003	15.79	2.66	20.95	.3187	3.44
3	.0008	14.04	1.83	64.92	.6122	2.21
4	.0012	21.05	0.99	43.06	.5026	1.35
5	.0003	15.79	0.65	28.08	.6362	0.80
Filter	.0016	28.07			.2288	0.23
Total	.0057					

BRINK IMPACTOR

Date 5-28-76 Run # B-12 Location outlet
Sample volume at STP (ft^3) = 0.908 Bar. Pressure (in Hg) = 30.07
Impactor flow rate (acfm) = 0.060 Temp in duct (°F) = 80.0
Concentration (grains/ft^3) = 0.072 Time (min) = 15.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% stated size	dm/d log D	Geo. Mean (μm)
Cyclone	.0000		12.85	100.00	.0000	16.05
0	.0001	2.38	7.82	37.62	.0080	10.01
1	.0001	2.38	4.45	35.24	.0070	5.30
2	.0002	4.76	2.65	30.48	.0152	3.43
3	.0005	11.90	1.82	18.58	.0330	2.19
4	.0004	9.52	0.98	69.05	.0260	1.34
5	.0007	16.67	0.64	52.39	.0450	0.80
Filter	.0022	52.38			.0417	0.35
Total	.0042					

Residence Time = 30 sec

BRINK IMPACTOR

Date 5-28-76 Run # B-14 Location outlet

Sample volume at STP (ft^3) = 0.734 Bar. Pressure (in Hg) = 30.07

Impactor flow rate (acfm) = 0.061 Temp in duct (°F) = 80.00

Concentration (grains/ft^3) = 0.040 Time (min) = 12.00

Stage	Net weight (gm)	% on stage	Stage cutoff (μm)	% < stated size	dm/d log D	Geo. Mean (μm)
Cyclone						
0						
1						
2	.0000		2.63	100.00	.0000	3.40
3	.0001	5.26	1.81	94.74	.0150	2.18
4	.0000	0.00	0.98	94.74	.0000	1.33
5	.0001	5.26	0.64	89.48	.0114	0.78
Filter	.0017	89.47			.0538	0.23
Total	.0019					

Residence Time = 56 sec.

BRINK IMPACTOR

Date 6-24-76 Run # B-16 Location outlet

Sample volume at STP (ft^3) = 0.986 Bar. Pressure (in Hg) = 30.10

Impactor flow rate (acfm) = 0.058 Temp in duct (°F) = 80.0

Concentration (grains/ft^3) = 0.096 Time (min) = 10.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% stated size	dm/d log D	Geo. Mean (μm)
Cyclone	.0000		15.07	100.00	.0000	14.17
0	.0001	2.78	7.36	97.22	.0125	10.20
1	.0001	2.78	4.53	94.43	.0108	6.00
2	.0003	8.33	2.69	86.12	.0334	3.49
3	.0002	5.56	1.86	80.56	.0222	2.24
4	.0007	19.44	1.00	61.12	.0634	1.36
5	.0006	13.44	0.66	41.67	.1000	0.81
Filter	.0015	41.67			.0437	0.33
Total	.0036					

Residence Time = 30 sec.

BRINK IMPACTOR

Date 6-24-76 Run # B-17 Location outlet

Sample volume at STP (ft^3) = 0.586 Bar. Pressure (in Hg) = 30.10

Impactor flow rate (acfm) = 0.057 Temp in duct (°F) = 85.0

Concentration (grains/ft^3) = 0.057 Time (min) = 10.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% stated size	dm/d log D	Geo. Mean (μm)
Cyclone						
0						
1						
2	.0000		2.70	100.00	.0000	3.50
3	.0002	14.29	1.86	85.71	.0152	2.24
4	.0001	7.14	1.01	78.58	.0100	1.37
5	.0002	14.29	0.66	64.29	.0191	0.81
Filter	.0009	64.28			.0264	0.33
Total	.0014					

Residence Time = 56 sec.

BRINK IMPACTOR

Date 6-28-76 Run # B-1B
Sample volume at STP (ft^3) = 0.585
Impactor flow rate (acfm) = 0.058
Concentration (grains/ft^3) = 0.048

Location outlet
Bar. Pressure (in Hg) = 30.06
Temp in duct (°F) = 80.0
Time (min) = 10.0

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% stated size	dm/d log D	Geo. Mean (μm)
Cyclone						
0						
1						
2						
3	.0000		1.86	100.00	.0000	2.34
4	.0001	5.55	1.01	94.45	.0100	1.36
5	.0003	16.67	0.66	77.78	.0436	0.81
Filter	.0014	77.78			.0411	0.23
Total	.0018					

Residence Time = 40 sec

APPENDIX C

ENTRAINMENT PROBLEM DUE TO FOAM DESTRUCTION

Foam destruction by the spinning disk method probably creates more of an entrainment problem than any other method of foam destruction. Even if the foam is allowed to destruct naturally, some water droplets are formed every time a bubble breaks. Using a condensation nuclei counter* to measure the particles from the destruction chamber at various conditions showed that many particles were generated just by foam breakage. After a test the chamber would remain about half full of foam. If clean air was allowed to flow over the foam at the same conditions as tested the foam destructed very slowly (2 to 3 hours). The particle count with clean air through a dry tube was about 100 particles per cc; with clean air over foam, the particle count was over 100,000 particles per cc; and with the foam destruction disk operating and foam flowing through the chamber, the particle count was over 1 million particles per cc--in the non-linear range of the counter where concentration is impossible to measure. (The particle count was in the non-linear range with the metallizing spray gun on or off.)

Other than for the few tests run to determine if an entrainment problem existed, the condensation nuclei counter was not a practical measurement device for this experiment.

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*Model Rich 100 manufactured by Environment/One Corporation